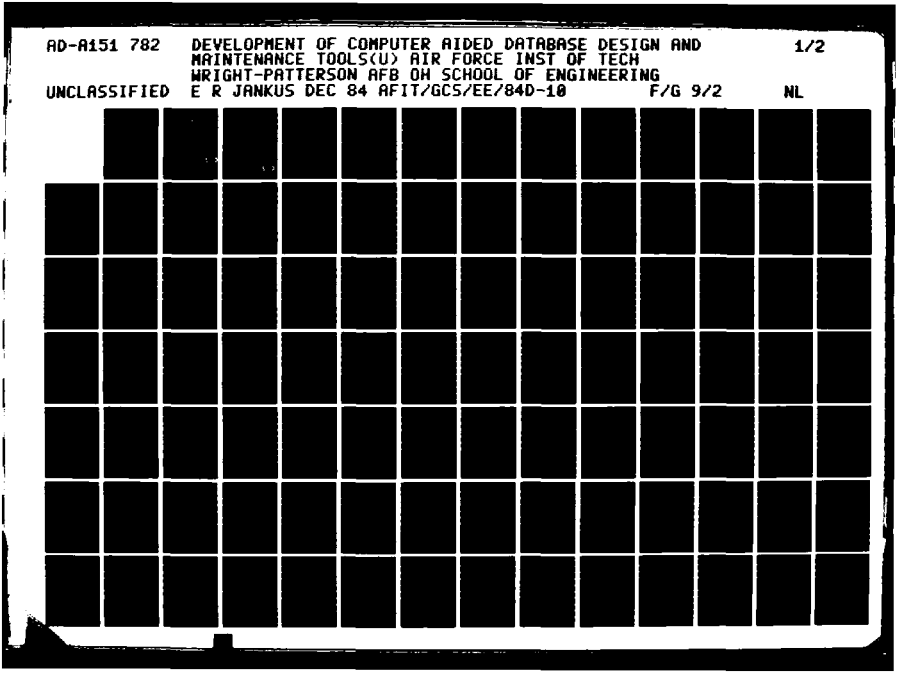
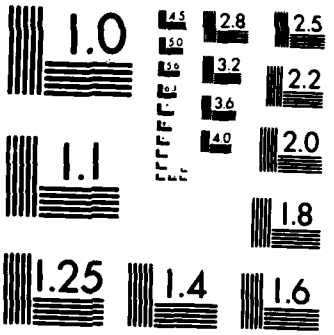

AD-A151 782 DEVELOPMENT OF COMPUTER AIDED DATABASE DESIGN AND MAINTENANCE TOOLS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING
1/2
UNCLASSIFIED E R JANKUS DEC 84 AFIT/GCS/EE/84D-10
F/G 9/2
NL



DEVELOPMENT of COMPUTER AIDED DATABASE DESIGN and MAINTENANCE TOOLS

THESIS

AFIT/GCS/EE/84D-10 Edward R. Jankus
2Lt. USAF

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GCS/EE/84D-10

DEVELOPMENT of COMPUTER AIDED DATABASE DESIGN and MAINTENANCE TOOLS

THESIS

AFIT/GCS/EE/84D-10 Edward R. Jankus
2Lt. USAF

AFIT/GCS/EE/84D-10

DEVELOPMENT of COMPUTER AIDED DATABASE DESIGN and MAINTENANCE TOOLS

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University (ATC)
In Partial Fulfillment of the
Requirements for the Degree of
Master of Science

Edward R. Jankus, B.S.
Second Lieutenant, USAF

December 1984

Preface

The purpose of this study was to perform a requirements analysis of the database administrator's tasks and identify those areas where CAD tools could be used to enhance the job. To this extent, it was decided to develop several user friendly systems for the DBA to define functional dependencies of relations in a relational database, and implement the code necessary to normalize unnormalized relations into Third Normal Form.

With the work accomplished in this thesis as a basis, other CAD database tools can be developed and the normalization tool extended to include up to Fifth Normal Form.

Throughout this thesis effort I have had a great deal of help from others. I would like to express my deepest appreciation and thanks to my thesis advisor Dr. Thomas C. Hartrum, for his patience, understanding and assistance in all of my times of need. I also wish to thank Dr. Henry Potoczny, who as my thesis reader provided many constructive insights. Not forgotten is Dan Zambon, LSI-11 lab engineer, who provided assistance and encouragement thoughout the implementation of this effort.

Finally, a special thanks to my wife Leilani for her concern and never-ending belief in me, and to my parents whom I can never thank enough.

Edward R. Jankus

Table of Contents

List of Figures

List of Tables

Abstract

This thesis investigated what the tasks of the database administrator are and detailed a list of computer aided tools to assist the DBA in performing those tasks. A selection criteria was established and two of the tools were implemented.

The first tool implemented was an interactive user-friendly Automated System for Normalizing Relations into Third Normal Form. The basis for this tool is the concept of a 'minimal cover' as presented by Jeffrey Ullman. If a minimal cover is deduced from the set of functional dependencies of an unnormalized relation, the resultant relations are in Third Normal Form.

The second tool explores the user friendly graphics area. It is a new front-end to the normalization tool that uses a mouse to allow the DBA to specify the functional dependencies that go into the normalization process. Together, these tools provide a very useful and complete system for the DBA to normalize relations in a Relational Database.

Development of Computer Aided Database Design and Maintenance Tools

I. Introduction

Background

The design, development and maintenance of a database can be a very time consuming and complex task. One of the many responsibilities of the database administrator (DBA) is to make sure that the database performs efficiently and consistently, with data integrity and limited data redundancy. A key to this is to ensure that the database is properly set up.

A relational database consists of tables (relations) which themselves consist of unordered sets of entries. Each of these entries is a meaningful collection of related information about the objects around which the relation was composed. Each table entry is called a tuple (row). Tuples are themselves composed of fields called attributes (columns).

In order for a database to perform with any merit, certain design constraints must be built into the system. Normalization theory, a useful aid in the database design process, is based on the concept of normal forms. A relation is said to be in a particular normal form if it satisfies a certain specified set of constraints.

There are numerous normal forms and generally the

'higher' the normal form that the DBA can get a relation into, the better. In other words, 3NF is more desirable than 2NF, which is more desirable than 1NF. This is true because the higher normal forms remove more of the undesirable properties that lead to the insertion/deletion anomalies that cause data inconsistency and loss of data integrity.

Normalization of relations is only one of the DBA's tasks that can be enhanced through the use of computer aided design (CAD) tools. CAD tools are user friendly interactive programs that often simulate the behavior of some system or task to the display console operator for further interactive design and testing. For example, CAD programs have been used extensively to design computer chips. Through interaction with the program, the user designs the chip layout and subsequently tests it on a simulator (another CAD tool) to determine if it works. The user can then go back and make any desired changes in the layout any number of times before a prototype is ever built. Such a procedure saves time and money and is used in many applications.

While a database is not a physical entity like a chip is, it too requires design layout and testing. It would therefore seem reasonable to try to create some CAD tools for the DBA to use to handle his complex and time consuming tasks faster, easier and more effectively.

Problem

The purpose of this thesis is to solve two problems. First, since the DBA has many tasks that he must perform, any time saved on any of the tasks is beneficial. Normalization is but one of the major tasks facing the DBA. The problem with normalization is that getting relations into the desired normal form is not always a trivial task. Like an art, it often takes much time and does not present an obvious answer. Obscure data dependencies may get past the DBA and foul the system.

The second problem is to define the various tasks of the DBA in the design, development and maintenance of a database, and determine what other tasks can be improved through the use of CAD tools. Hence, this study should have direct application in the rapidly expanding database area.

Scope

The requirements analysis of the DBA's tasks was performed to identify those areas where CAD tools could be used. From the outcome of this search it was determined that two tools would be implemented in this thesis.

The first tool is a tool to normalize unnormalized relations into Third Normal Form. This entails completing the work started by Travis [6] in this area, and carrying it out to generate up to 3NF. In order to accomplish this, all of the code that Travis wrote was translated to Whitesmith 'C'. There are several reasons for doing this. Whitesmith

'C' is a more versatile language and has a better compiler than the UCSD Pascal used by Travis, and the UCSD used by Travis is no longer being run in the LSI-11 labs. In addition, the interactive portion of Travis' system that allows the DBA to determine functional dependencies was redesigned to make use of the some of the capabilities of 'C' and the H-29 terminals.

The second tool selected complements the normalization tool. It is a completely redesigned user friendly front end for the normalization tool that uses a mouse to make it easier for the DBA to input functional dependencies.

Approach

In order to accomplish this study, first an in-depth literature review was undertaken to explore other current efforts in computer aided database design, and to find those areas of the DBA's tasks that would benefit most from computer aided tools. Very little work has been recorded in these areas. With the literature review completed, the next step was to detail the findings and select the tools to be implemented.

The focus of the study then turned to implementing the normalization tool. The first step was to examine the design and code already written by Travis [6], to determine how it works and to complete the design. Taking a top-down structured approach, and using various graphics and user interface concepts, the remaining modules were coded and

tested until they worked for 3NF.

Once the normalization tool was completed, the attention of the study was directed towards interfacing a Summagraphics mouse to the LSI-11 system and designing the interface to use the mouse to input the functional dependencies used in the normalization process. This interface was designed in a top-down structured fashion and implemented.

Finally, recommendations for future work on computer aided database design were noted and detailed in the conclusion of this thesis.

Sequence of Presentation

The remainder of this thesis is divided into five chapters and four appendices. Chapter II is the requirements definition chapter that describes the DBA's tasks and outlines some of the possible tools that can be implemented to assist the DBA. Chapter II also details the selection of the tools implemented and explains why they were selected.

Chapter III details the normalization process and presents an overview of normal forms. It details the concepts of minimal cover that is used as a basis for the normalization tool and presents the test case used to test the software. Also included is a section on implementation details of how the software is designed and how it works.

Chapter IV presents a discussion of various methods for inputting functional dependencies and selects both of the interfaces implemented to specify functional dependencies for

the normalization tool. The methods selected are an improved version of Travis' keyboard entry system and a method which uses a mouse to input the functional dependencies.

Chapter V details the Normalization tool driver and how it works. The chapter also details the keyboard entry and mouse method for inputting functional dependencies.

Chapter VI presents the conclusions obtained from performing this thesis and recommendations for future research and projects.

The four appendices at the end of this thesis contain the User's Guide to the Normalization tool, an article summary of this thesis, a detailed discussion of the peripheral devices used, and the pseudo code developed by Travis.

II. REQUIREMENTS DEFINITION

Before designing tools for the database administrator to use, it is necessary to answer the somewhat nebulous question, "what are the tasks of the database administrator?". To answer this question several interviews and a literature search were performed. A good overview of the DBA's duties was found in the text by Weldon [12], and includes among other things, the following suggestions:

Database Planning Phase:

1. Define database goals in support of organizational goals.
2. Develop and revise plans to achieve database goals, in particular, plan the transition to the database environment.
3. Assess the impact of changes in technology and information requirements on the database.
4. Evaluate and select hardware and software to be used to support database operations.

Database Design Phase:

5. Control the database design process through the integration of data needs and the scheduling of application development.
6. Provide expertise on methods for requirements analysis, database design and on the DBMS.
7. Make decisions concerning design trade-offs.
8. Guide and consolidate logical database design, and provide expertise in data modeling, defining data, and integrating user's views.
9. Perform the physical design of the database, and select storage and access methods.
10. Maintain a physical data description or data dictionary.

Database Operation and Control:

11. Set and enforce data standards for data definition, application coding, testing and system design.

12. Develop and install procedures for error detection and resolution.

13. Set policies for database backup and recovery.

14. Establish and enforce a comprehensive database security policy that includes user authorization, internal controls, and controls on personnel.

15. Develop and monitor database performance indicators.

16. Resolve database operational problems through fine tuning, reorganization, or redesign.

17. Maintain the DBMS and related software.

Database Usage:

18. Build, maintain, and distribute information about the database to users, operators, and system developers.

19. Select the data dictionary package to be used.

20. Define and enforce standards for data naming, coding, documentation, and system development procedures [12:12-13].

Database Design

The design of a database remains somewhat an art, often marked by the use of ad hoc methods of design. These ad hoc methods often create a product that falls short of the target. The reason is that there are many things to be considered when designing a database and ad hoc methods rarely take all things into consideration. What is needed is a more systematic and structured approach to database design, one that lends itself to the use of computer aided design tools.

The DBA faces several major problems when designing a database. First, he must determine the data requirements, i.e., the portion of the 'world' to be represented. As with any major software development project, finding out what the users really need/want is one of the most difficult tasks, for often the user himself is unsure of what he really wants. Secondly, the DBA must consolidate the requirements of several applications or departments into a unified set for shared use. Third, the DBA must design for the future, that is, anticipate changes in usage and design so that changes in the system can be made without an entire redesign.

Once the data requirements are established, they must be mapped into the logical data model and the physical storage structures that are supported by the DBMS. Regardless of the DBMS used, the database design should follow the basic standards of database design in order to minimize data redundancy, avoid insertion and deletion anomalies, provide adequate performance, and provide for ease in design changes [13:283].

One structured iterative methodology for logical database design suggested by Hubbard [5], and Vetter [10], goes as follows:

1). Derive the local view (the representation of the data elements and relationships that are required in the database to support a given function), for one or two of the most important functions or applications to be supported by the database. This will form the framework of the design.

2). Invoke conceptual design procedures to gather, record and edit the data requirements of the organization.

3). Organize the data requirements into structures such as segments and hierarchies, for the given DBMS to be used. This logical design along with the conceptual design, forms the logical model of the database.

4). Select the next most important function or application and add its local view to the model and rederive the logical model.

5). If any incompatibilities exist between the old and new logical models, identify them and make corrections (trade offs).

6). Continue this process until all functions or applications are integrated and all inconsistencies, such as naming inconsistencies, are removed.

7). The edited composite model represents the unstructured internal view of the integrated database, but it is not yet complete. To complete the process, future requirements should be considered and processed in order to help insure that the database structure developed is one that is flexible to change.

8). Finally, the result of this procedure yields the complete model representing the unstructured internal view of the integrated database. From this model the complete logical model and then a physical model can be derived.

As a practical consideration, this type of structured iterative approach is usually not feasible by using purely manual design techniques. Such a methodology is desirable however, because it can provide a significant quality control capability to the design process [5:23]. For these reasons, all of the computer aided design tools discussed will be useful in achieving such a structured iterative design.

Computer Aided Design Tools

Research and interviews into the idea of using computer aided design tools to assist the DBA have met with mixed results. First, since database design is still pretty much an art, most people could not really come up with areas where they felt computer aided design tools would be useful. However, continued literature research revealed several good design methodologies which in themselves provide opportunity for computer aids. Many of the ideas found deal with providing the DBA with some sort of report to assist him in design trade-offs, finding errors in design, and increasing design efficiency while at the same time reducing design time. The following is a list of potential design tools discovered through interviews and an extensive literature review:

For use in general database design:

1. One aid to database design would be a tool to help the DBA determine the functional specifications that the end user desires. By producing exact formats of the desired screens and reports, computer aids can help end users see how well the report will meet their needs. Experience also indicates that when this type of approach is used, the data requirements are less likely to change during the design process [5:24].

2. When integrating the various user's views, an alphabetical list of names along with where they are used, and a list showing the contexts in which all the qualifications of the data names are used, would be helpful in finding synonyms, homonyms, and other naming inconsistencies. It could also be used to detect problems and inconsistencies in usage, format and meaning of the data item in the various local views [5:47].

3. An 'intersecting data elements report' containing a list of all data elements having more than one key. Such a list could be used to help identify naming inconsistencies

and redundant data [5:96].

4. A data element usage matrix showing which data elements are used by which functions [5:97]. This matrix is more or less a condensed form of the list of #2, in a somewhat graphical representation.

5. An interactive graphics display for the cononical design technique. It could draw the graphs and list the attributes and relations as the entities were added to the graph. The graph defines the records with their keys and attributes and shows the associations between the records [1:65].

6. Use of PSL/PSA to analyze requirements, design the global logical database, define the database process, design the physical database, and simulate database operation [2].

7. A tool to assist the DBA in conveniently meshing individual subschemas or views together into the global logical model. Naming and other inconsistencies would have to be resolved by the DBA, perhaps interactively with the use of some of the forementioned design reports [10:73].

8. A local view report that gives the contributions of each local view in the final logical view derived. This report could be useful to a DBA who wants to evaluate the effect of an application on the overall design [5:97].

9. Physical design tools. An on line system for the designer to make and specify physical design choices and options. A conversational terminal session can guide the designer in selecting device type, access methods, block size, secondary data set groups, pointer options, and ordering choices [5:135-136].

Tools for relational database design:

10. A list of the transitive dependencies identified and removed from the design. This could be useful to the designer who may want to reinsert some of the dependencies, at the expense of redundancy, in order to gain performance and validity benefits [5:95].

11. A list of functional dependencies removed to obtain functional dependence. This could be used by the DBA to reinsert a dependency if it is important to the way the organization functions. At a cost of increased data redundancy, it may be better to have the dependency exist for performance reasons, or to more accurately or

conveniently represent the organization's requirements as they really are [5:128].

12. Identification of domains. A list of domains represented by the data elements, and of which elements (key or attribute) belong to which domain. The primary use of this would be for determining the potential for natural joins between derived relations [5:122].

13. Produce performance weights and relation sizes to assist the designer with efficiency considerations such as:
    a) frequency of use of individual relations
    b) frequency of use of the attributes within a relation
    c) frequency of need for joins [5:125-126].

14. A derived relations report showing the most frequently derived relations [5:127]. If the need for space-and-time costly joins is too great, it may be desirable to create an extra view to contain that information that is derived via the join operation. This report and that of #15, go hand in hand with the frequency reports of #13.

15. A suggested joins report listing relations having common elements. This could note which relations must be joined to support the functional requirements of the database [5:127]. Also possible is a list of all the other natural joins that are dynamically possible in the database. This can be useful when new applications or functions are added to the database.

16. A redundant attributes report containing a list of data elements appearing as attributes in more than one relation [5:128].

17. A user friendly interactive tool to take a set of functional dependencies, as specified by the DBA, and reduce the unnormalized relations to Third Normal Form [6]. Such a tool would help the DBA handle this complex and time-consuming task faster, easier, and more effectively.

18. A user friendly (graphical or voice) interface to point to attributes when defining functional dependencies. Such a tool could be especially useful as part of a normalization tool that requires the user to specify the functional dependencies for the normalization process.

19. A method for documenting the changes which relations experience during normalization. This could give the DBA and users access to what actually occurred through the execution of the normalization process [6:71].

20. A report stating which relations are affected by the addition of new fields. Such a tool could be useful to the DBA who may need to make trade-offs in design when a new function must be added to the database. It is also useful as an integrity constraint to insure that no relations are inadvertently missed.

21. A tool to generate and help the designer evaluate alternative minimal covers to best suit the organization's needs and/or requirements. This could be a tool to generate the 'best' set of functional dependencies to meet the organization's needs, possibly in terms of performance or convenience.

Selection Criteria

After defining the DBA's tasks and examining some possible database design tools, it was necessary to choose which tools would be implemented in this thesis. In order to select the tools to be implemented, five selection criteria were used. Each of the criteria was applied to each of the database design tools, and the results are shown in matrix form in Table 1.

The first set of criteria deals with the utility of a given tool. Some tools may be useful in only one of the three design phases (conceptual, logical, or physical), while other tools may be useful in one or more of these phases. In general, a tool that can be used throughout the database development process is more valuable to the DBA than a tool that has limited use. This statement requires some qualification. In general, a tool that can be used in more than one phase is more useful than one that is used in only one phase, unless the latter is a tool that vastly reduces

the design efforts of a given phase. For example, a tool to normalize relations in a relational database would take care of the majority of work required in the logical design phase, and as such, would be a very important tool even though its use is limited to the logical design phase.

In the selection criteria matrix of Table 1, each tool received an 'X' to represent its usefulness in one or more of the design phases.

The second criteria is that of feasibility. Given the current AFIT environment, time constraints and equipment, does it seem feasible to implement a given tool in the short-run, or even the long-run? Each tool has an 'S' under it if it is achievable in the short-run (one thesis), an 'L' if it is achievable in the long-run (several theses), or a '?' for a tool that is not implementable given the current set of constraints.

In selecting a tool for implementation as part of this thesis, it was desirable to select from those that were feasible in the short-run. The reasoning behind this decision is two-fold. First, if the tool could be designed and implemented in the short-run, it would be possible to get useful feedback about the tool, by letting one of the database classes here at AFIT work with it. Second, by designing and actually implementing a tool, it would be assured of development, and not fall by the wayside waiting for somebody else to finish it. In other words, a usable

Table I
Database Design Tools Selection Matrix

Criteria / TOOL	Utility of tool: in Conceptual Design Phase	in Logical Design Phase	in Physical Design Phase	Feasibility	Data model Dependent	Interactive	Designer Appeal
1	X			L	G	Y	4
2	X	X		S	G	N	2
3	X	X		S	G	N	1
4	X	X		S	G	N	1
5		X		L	G	Y	4
6	X	X	X	?	G	Y	1
7		X		L	G	Y	3
8		X		S	G	N	2
9			X	L	D	Y	1
10		X		S	D	N	4
11		X		S	D	N	3
12		X		S	D	N	2
13		X		L	D	N	1
14		X		S	D	N	2
15		X		S	D	N	2
16		X		S	D	N	3
17		X		S	D	Y	5
18		X		S	D	Y	5
19		X		S	D	N	3
20		X		S	D	N	2
21		X		L	D	Y	5

Key:

L:	Long-term	G:	General	Y:	Yes
S:	Short-term	D:	Data Model Dependent	N:	No
?:	Unknown				

finished product would result.

The third set of selection criteria deals with whether or not a tool is dependent on a particular data model (relational, network or hierarchical). Tools that are data model dependent are denoted with a 'D' in the selection matrix, while the tools that are general in nature and independent of the data model used, are denoted with a 'G'.

In selecting a tool for this thesis, it was desirable to select one that was either general in nature or dependent on the relational data model since those tools could be more easily implemented given the current AFIT environment.

The fourth selection criteria concerns the interactive design aspect. Interactive tools can aid the database designer in making decisions and can reduce the time needed for design by doing most of the work required. Interactive tools can be very user-friendly and easier to use than report-generating tools because they do not generate a paper mill for the DBA to read and interpret. Each of the tools has a 'Y' under it if it is interactive, and a 'N' if it is not. In selecting tools for implementation in this thesis, emphasis was put on those tools which are interactive.

The last selection criteria is the all-encompassing, "appeal to the author". I rated each of the tools on a scale from 1-5 (low-high), for their personal appeal. From my literature research and personal interests, I have come across tools that are more interesting to me than others,

namely, interactive tools and tools for relational or general design. I believe this to be a valid selection criteria since it certainly helps a project to have a particular interest in the work one is doing.

The Selection

After considering the tools and selection criteria, the decision was made to work on implementing two of the forementioned tools. This section explains which of the tools were selected and why.

The first tool to be implemented is the tool to take a set of functional dependencies of relations for a relational database and reduce these unnormalized relations to 3NF (tool #17). The reasoning for picking this tool follows.

The normalization tool is a tool that is useful only in the logical design phase, but it is a tool that does most of the work that has to be done in the logical design phase. Once the functional dependencies are specified and the relations normalized, the task is essentially complete. None of the other tools has such a profound impact on a given phase of the design process.

The normalization tool is definitely feasible within the scope of this thesis. This tool would actually complete the thesis by Travis [6], which set the framework for a system to define the functional dependencies of relations for the normalization tool to use. The work to be completed entails the completion of the coding and implementation of the part

that does the actual normalization. When completed, this tool will represent a usable finished product.

This tool is dependent on the relational data model but that does not pose any problem since the groundwork for this tool has already been laid by Travis. Also, relational database systems are becoming very popular because of their relative simplicity, so any useful tool that can help in this growing area is beneficial.

The fact that this is an interactive tool makes it even more attractive. As previously mentioned, interactive tools can be very user-friendly and much easier to use than report-generating tools. As such, this tool will be much easier to use than trying to do the normalization process by hand.

Finally, the normalization tool has a lot of appeal. It can save the DBA a vast amount of time and perform the normalization process more effectively, freeing the DBA to tend to his/her other duties.

The second tool to be worked on is the user friendly (graphical or voice) interface to specify attributes when defining functional dependencies (tool #18). This tool will go along nicely with the normalization tool being developed. It could be used to specify the functional dependencies required as input to the normalization process.

This tool is of primary use in the logical design phase, along with the normalization tool. The difference is that this tool is an interface to the other. It is through this

interface that the DBA must interact with the normalization tool. In order to make the normalization tool more user-friendly and effective, a good interface is needed.

This tool is feasible under the time constraints of this thesis, and equipment such as voice and various graphics tools are available for use here at AFIT. The interface would be the finishing touch for the normalization tool, so the concern about data model dependence is not significant. Furthermore, the use of various graphics devices in this interface may be applicable for use in tools designed for other data models.

The interface will obviously be interactive in order to make the DBA's job easier. This will also help to promote the use of the tool. The user-friendly interface also has a great deal of designer appeal. It is part of a wide-open area, where many new ideas can be conceived, developed and evaluated for their potential. As new and better graphical tools are developed, interest in the the man-machine interface area is certain to grow.

In summary, the normalization and interface tools were chosen for implementation because they go together well to constitute a very useful and complete tool for the DBA in the logical design phase of a relational database. Furthermore, the design of the the user-friendly interface is a very interesting and challenging area that holds much promise in the design of future computer aided design tools.

III. NORMALIZATION PROCESS REQUIREMENTS ANALYSIS

Introduction

Before discussing the normalization process developed by Travis and implemented in this thesis, a brief overview of the concepts necessary to understand normalization in general is given in this chapter. From there, the discussion centers around the actual methodology used to normalize relations in this thesis. Finally, implementation and testing details are presented for the normalization tool.

Background

At this point, the term functional dependency (FD) becomes significant. Functional dependency is defined as follows:

> Given a relation (table) R, attribute (column) Y of R is functionally dependent on attribute X of R, if each X value in R has only one Y value in R associated with it [4:240].

In other words, each value of the attribute X will functionally determine one and only one value for attribute Y in relation R. Throughout this thesis, notation of the form A --> (B,C), denotes the functional dependency that attribute 'A' functionally determines attributes 'B' and 'C'. For example, in order to specify that a persons 'social security number' (SSNO) determines his/her 'NAME' we would write, SSNO --> NAME, meaning that any given ssno will determine one and only one name.

Another important concept is that of full functional

dependence. According to Date [4:241],

"Attribute Y is fully functionally dependent on attribute X if it is functionally dependent on X and not functionally dependent on any proper subset of X."

In other words, there can not exist a proper subset X' of the attributes that make up X such that Y is functionally dependent on X'. For example, in the SUPPLIER relation shown in Figure 1 below, attribute CITY is functionally dependent on the composite attribute (SUPPLIER,STATUS). CITY is not fully functionally dependent on (SUPPLIER,STATUS), however, because CITY is also functionally dependent on SUPPLIER alone. Throughout this paper, the term functional dependence will be taken to mean full functional dependence unless otherwise stated.

SUPPLIER	SNAME	STATUS	CITY
S1	Smith	20	London
S2	Jones	10	Paris
S3	Blake	30	Paris
S4	Clark	20	London
S5	Adams	30	Athens

Figure 1. Supplier Relation [4:92]

The normalization process uses the predefined functional dependencies to produce a collection of new relations, equivalent to the original relation, but in a more desirable form from the database point of view. Numerous normal forms exist and generally the higher the normal form that the DBA can get a relation into, the better (3NF > 2NF > 1NF). This

improvement results from the higher normal forms removing more of the undesirable properties that lead to the insertion and deletion anomalies that ultimately cause data inconsistency and loss of data integrity.

Another important concept is that of keys. A key is a collection of one or more attributes with values that can uniquely identify each of the tuples (rows) of the relation. Some relations contain more than one attribute combination that uniquely identifies tuples in the relation. All of the attribute combinations containing this property are called candidate keys. The database administrator must decide which candidate key to use, and this key then becomes the primary key.

First Normal Form

A database designer often starts with a raw relation or data of the form:

SUPPLIER	CITY	STATUS	PART#	QUANTITY
S1	London	20	P1	20
			P2	10
			P3	1
S2	Paris	10	P1	12
			P4	18

The rules of normalization state that a relation in 1NF contains attributes with atomic (single) values only. A trivial process, placing a relation into 1NF requires that the attribute(s) consisting of multiple values be broken up into two or more single attributes as shown in relation FIRST

in Figure 2 [4:238].

SUPPLIER	PART#	QUANTITY	CITY	STATUS
S1	P1	20	London	20
S1	P2	10	London	20
S1	P3	1	London	20
S2	P1	12	Paris	10
S2	P4	18	Paris	10

Figure 2. Relation FIRST.

Getting a relation into 1NF allows us to refer to each attribute separately (needed for updates) and provides the basis for further normalization.

Second Normal Form

Examining relation FIRST of Figure 2, it is easy to see that some problems exist. First, the relation contains a lot of data redundancy. The same CITY and STATUS values exist for all like values of SUPPLIER. This redundancy of data becomes very expensive in terms of the extra storage required to hold the redundant data and in terms of the multiple updates required, for example, if a SUPPLIER's status changes. Every tuple in the relation would have to be searched to find all of the tuples containing the given supplier. This could take an unreasonable amount of time for large relations. Also, if even a single tuple is missed in the update, the data would become inconsistent [4:243].

The definition for 2NF states that a relation is in 2NF

if:

1). it is in 1NF
2). every attribute not a member of a candidate key is functionally dependent on each candidate key of the relation [4:246].

Relation FIRST of Figure 2, while in 1NF, fails to satisfy the requirements for 2NF. In order to get it into 2NF the DBA must first determine the key for the relation. One possible key could be (SUPPLIER,PART) --> (CITY,STATUS,QUANTITY), but it can also be seen that SUPPLIER alone determines CITY & STATUS. When a subset of the key determines some of the attributes, a partial dependency exists, often causing data redundancy [4:244]. The DBA removes these partial dependencies by splitting the table up into two or more separate tables based on the functional dependencies of the relation (see Figure 3). For example, since SUPPLIER --> (STATUS, CITY), a new relation (table) is constructed containing these attributes. Similarly, since (SUPPLIER, PART#) --> QUANTITY, a separate table is constructed for those attributes.

SUPPLIER	STATUS	CITY
S1	20	London
S2	10	Paris

SUPPLIER	PART#	QUANTITY
S1	P1	20
S1	P2	10
S1	P3	1
S2	P1	12
S2	P4	18

Figure 3. Relations SECOND and SPQ.

Third Normal Form

The relations SPQ and SECOND have eliminated the data redundancy problem but a problem still exists in the SECOND table. SECOND has a non-key attribute (STATUS) dependent on the key (SUPPLIER) thru another attribute (CITY). In other words, SUPPLIER --> CITY; CITY --> STATUS; and SUPPLIER --> STATUS thru CITY. The dependency of STATUS on SUPPLIER, although it is functional, is also transitive via CITY since each SUPPLIER value determines a CITY value and this in turn determines the STATUS value. This implied transitive dependency is not allowed in 3NF relations because this transitivity leads to update problems [4:248]. For example, it is not possible to state that a supplier in Rome has a status of 50 until there is an actual supplier in Rome because until such a supplier exists, there is no appropriate primary key value. Likewise, deletion problems also exist.

Examining the functional dependencies of relation SECOND reveals that it can be put into 3NF by breaking it up into two new tables, SC and CS (see Figure 4), in order to reflect the functional dependencies SUPPLIER --> CITY and CITY --> STATUS.

SUPPLIER	CITY
S1	London
S2	Paris

CITY	STATUS
London	20
Paris	10

Figure 4. Relations SC and CS.

Even with the data split up into several separate relational structures, it is still possible to obtain the original structure if so desired. Taking a join of the relations created gives back the original relation, FIRST. Called a lossless decomposition because no information is lost, this desirable feature plays an important role in database decomposition [4:247].

An aid to the database administrator, third normal form (3NF) allows the database to grow and evolve naturally. With relations in 3NF the database contains only limited data redundancy, and updates are possible without the problems encountered in the previous normal forms. For example, it is now possible to have information on cities and their status, where no supplier yet exists.

Concept of Minimal Cover

One way to normalize relations into 3NF, and in fact the method used in this thesis, is based on the concept of a minimal cover. By constructing a minimal set of functional dependencies, the resultant family of dependencies is automatically in 3NF [9:223-225]. We say that a set of functional dependencies, F, is minimal if:

1). Every right hand side (RHS) of a functional dependency in F has a single attribute, such as ABC --> D. This rule guarantees that no attribute on the RHS is redundant [9:224].

2). For all dependencies X --> A in F, if the dependency

X --> A is deleted, the resulting family is no longer equivalent. This rule guarantees that no dependency in F is redundant, since if a redundancy existed, the deletion of X --> A would leave an equivalent family of functional dependencies.

3). For no functional dependencies X --> A in F, and proper subset Z of X, is F - [X --> A] U [Z --> A] equivalent to F. This rule says that no attributes on the left hand side (LHS) of the dependency are redundant [9:224].

Obtaining a minimal cover is a straightforward process. The first step is to reduce the RHS of each functional dependency defined by the DBA, to a single attribute. The new set of dependencies will have the same set of determinant attributes (those on the LHS), but only a single attribute as the dependent set (on the RHS).

For example, if F is a family of functional dependencies for a relation and consists of the following dependencies:

```
 B --> X
AB --> CDE
AC --> BE
 C --> XB
 A --> CX
 X --> B
DE --> AB
```

then the result of this decomposition process would be the new set of functional dependencies:

```
 B --> X
AB --> C
AB --> D
```

```
AB --> E
AC --> B
AC --> E
 C --> X
 C --> B
 A --> C
 A --> X
 X --> B
DE --> A
DE --> B
```

An important concept of the above decomposition is that all previously defined dependencies can still be obtained from the new set, so there is no loss of information [9:225]. This is an example of a lossless decomposition.

The second step is to remove dependencies that contribute redundant definitions. In other words, remove those dependencies that have a subset of the original dependency while determining the same single attribute. For example, the dependencies broken out by step one can be reduced to the set:

```
 B --> X
AB --> D
AB --> E
AC --> E
 C --> X
 C --> B
 A --> C
 A --> X
 X --> B
DE --> A
DE --> B
```

The result was the elimination of the two dependencies AB --> C and AC --> B. AB --> C was eliminated because the two dependencies AB --> C and A--> C, achieve the same result

but A --> C does it more efficiently. Since A --> C has a determinant set of attributes that is a subset of AB --> C, the procedure says to eliminate the dependency with the larger set of attributes and keep the dependency with smaller set. In other words, since 'A' will get you 'C', there is no need to carry along the extra attribute 'B'. The same argument holds for AC --> B and C --> B.

The third step in developing a minimal cover is to remove any redundant explicit transitive dependencies that exist. Any implicit transitive dependencies that exist are removed in the final step of the process by separating them into different relations. This is explained further in the last step. With the remaining dependencies from step 2

```
 B --> X
AB --> C
AB --> D
AB --> E
AC --> B
AC --> E
 C --> X
 C --> B
 A --> C
 A --> X
 X --> B
DE --> A
DE --> B
```

we examine the RHS of each dependency and see if there are any dependencies with a single attribute on the determinant (LHS) that are the same as the attribute in question. The first dependency, B --> X has the first attribute to satisfy the conditions searched for, since attribute X is also found

on the LHS of X --> B. With this in mind, since B --> X and X --> B, it can be trivially deduced in this case that B --> B implicitly. The final check is to see if this implied dependency exists explicitly. Since it does not exist explicitly as well as implicitly in this example, nothing can be removed in the first pass.

The fifth dependency, C --> X, is the next dependency to meet the criteria, since attribute X is also found on the LHS of X --> B. With this in mind, since C --> X and X --> B, it can be deduced that C --> B implicitly. A search of the list of dependencies reveals that C --> B also exists explicitly as well as implicitly, therefore the explicit dependency should be removed to eliminate the transitive dependency. Similarly, since A --> C , C --> X and A --> X all exist in the list of dependencies, A --> X must be removed.
This process is repeated for the entire list of dependencies until all redundant transitive dependencies have been removed and the list of attributes on the RHS is exhausted.

The result of these three steps, shown below, is a minimal cover (set) F for the given original unnormalized relation. Each dependency, if treated as a separate relation, would satisfy the definition of a 3NF relation [9:242].

```
 B --> X
AB --> D
AB --> E
AC --> E      Minimal
 C --> X       Cover
```

A --> C
X --> B
DE --> A
DE --> B

This normalization process can be taken two steps further to save space and reduce the amount of redundant data that is stored in memory. First, rather than create a relation (table) for each of the functional dependencies in the minimal cover, it would be better to first collect those functional dependencies with identical determinant attribute sets (LHS) into groups. Doing this to the minimal set above yields the new "minimal cover":

B --> X
AB --> DE
AC --> E
C --> X
A --> C
X --> B
DE --> BA

Now instead of 9 relations and 24 attributes, it is possible to build 7 relations with a total of only 19 attributes. This step can result in substantial savings in space, especially for large databases.

It is possible to further reduce the number of relations created by realizing that several of the functional dependencies contain the same attributes, although in a different arrangement, but the same none the less. Since they do contain the same attributes, there is no need to create a separate relation for each since this would in

essence create a duplicate table. For example, in this case X --> B and B --> X. A relation created containing B and X embodies both dependencies so it is only necessary to carry one of them along. This results in the elimination of X --> B. Similarly, since both AB --> DE and DE --> AB still remain and contain the exact same attributes, DE --> AB can be eliminated. This step was not considered in Travis' original design.

The final step is to actually create the new relations from the remaining functional dependencies. Creating a new relation for each of the remaining dependencies guarantees that any implicit transitive dependencies will be removed (remember all explicit transitive dependencies were removed earlier in the third step of the process). The new relations are composed of the attributes that were involved in the functional dependency that the relation was constructed from. Each of the attributes of the new relation will have the same domain as was in the original relation. The results of the normalization process for this case would look like the following 5 relations:

```
Relation Name:  NewRelation1
   Attributes:  BX
          Key:  B

Relation Name:  NewRelation2
   Attributes:  ABDE
          Key:  AB

Relation Name:  NewRelation3
   Attributes:  ACE
          Key:  AC
```

Relation Name: NewRelation4
Attributes: CX
Key: C

Relation Name: NewRelation5
Attributes: AC
Key: A

The new relation names would have to be supplied by the DBA at the time of their creation.

The result of this procedure yields relations in 3NF. It is coincidental that there were 7 functional dependencies defined originally and 5 resulting relations. In general, there is no way to predict the precise outcome of the procedure because if the functional dependencies were supplied in a different order, a different but equally valid minimal cover would probably result. Regardless of the order the functional dependencies are supplied, however, the procedure is guaranteed to remove data redundancy and transitive dependencies, resulting in 3NF relations [9:224].

Normalization Implementation

The normalization portion of the system consists of 7 major modules and is based somewhat on the pseudo-code developed by Travis [Appendix D]. All code is written in Whitesmith 'C' so as to be compatible with the LSI-11's in the AFIT digital engineering lab. Module NORMALIZE is the executive driver module that calls each of the 6 submodules in turn in order to normalize relations in accordance with Ullman's concept of a minimal cover. Each module is designed

to perform one specific function. The modules are sequential in nature, in other words, one procedure follows the other with the output of one procedure as the input to the next procedure until the last procedure is executed. In addition, normalize calls a print function, PRINT_FDS, after each step in the process in order to provide the DBA with a step by step view of the functional dependencies as they go through the normalization process. This information is stored in an archive file along with the names of the new relations created and the old relation definitions, to provide an audit trail in case questions arise in the future about the new relations, the old relation or the functional dependencies that were defined. This information can be very useful in performing joins on the database in order to get back the original relation. It can also be used as a learning tool to demonstrate the steps in the normalization process. This is in effect an implementation of tool #19 (see Chapter 2).

The 6 modules that NORMALIZE calls to perform the actual normalization are: BREAKOUT, REMOVE_SUBS, TRANS_DEPEND, REGROUP, REMVE_DUPL and NEWREL. Each routine performs one of the steps in the normalization process as just defined in the previous section. A structure chart and data flow diagram for the normalization process can be found in Figures 5 and 6, respectively.

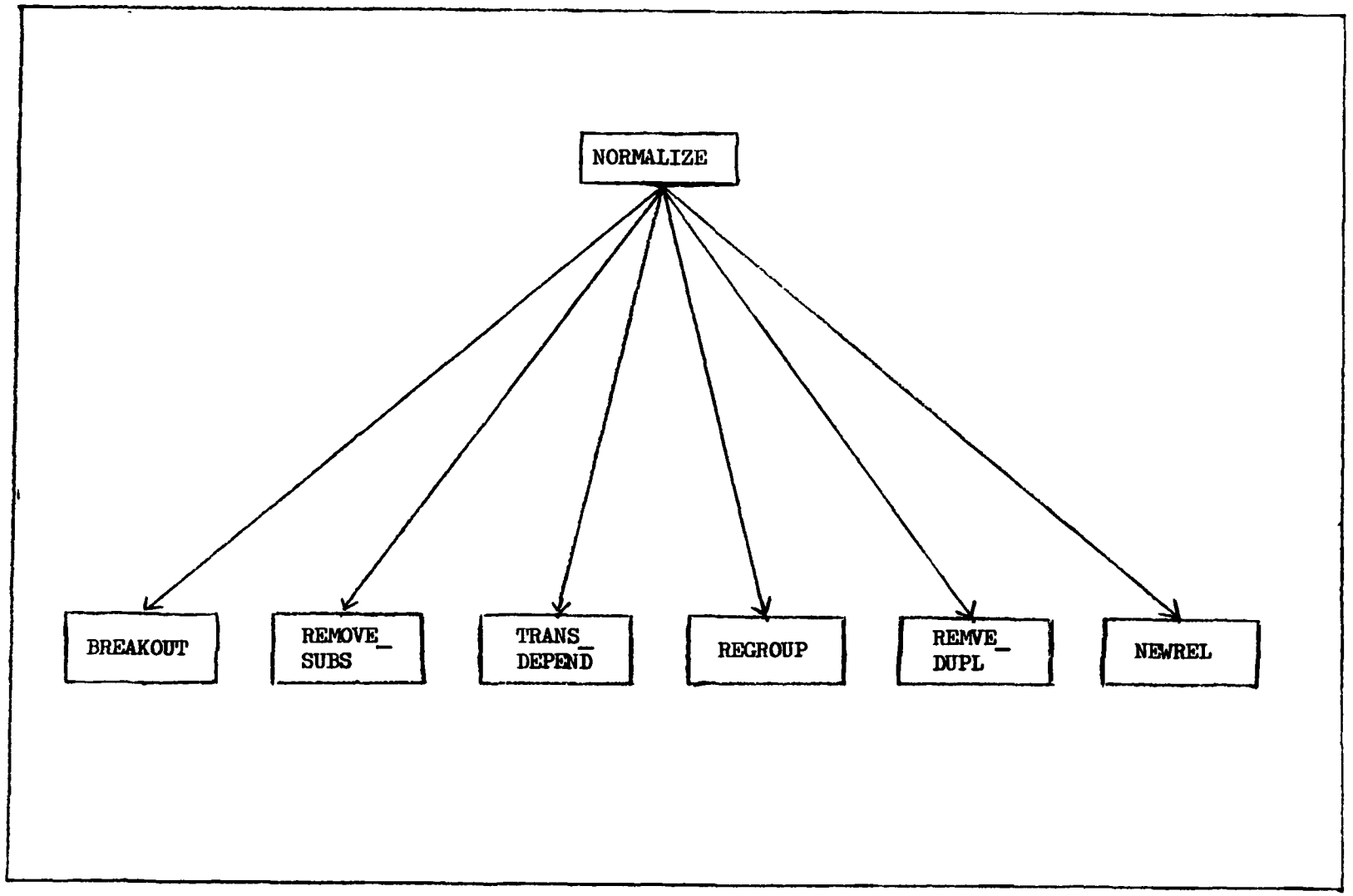


Figure 5. Structure Chart for Module NORMALIZE

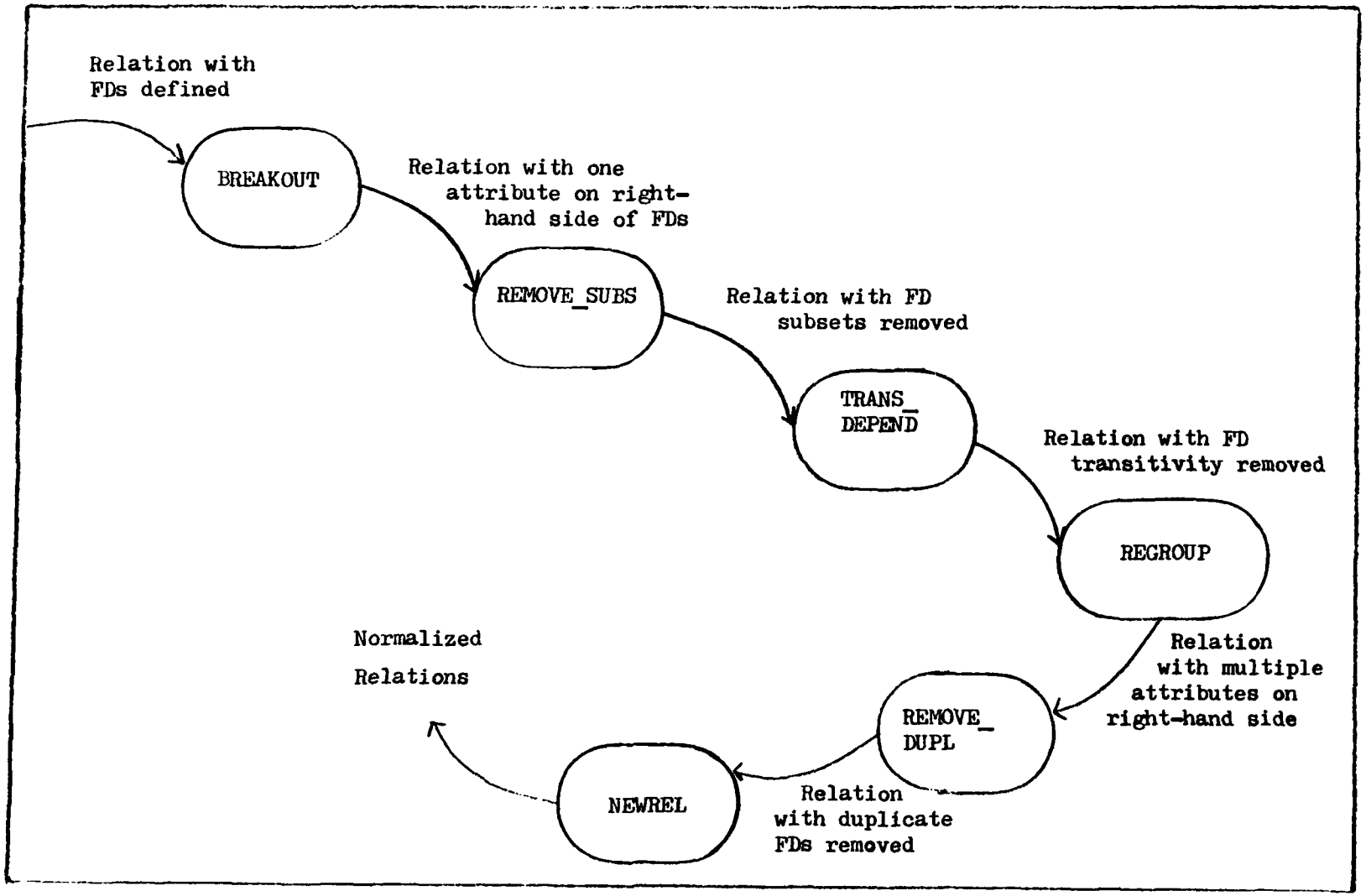


Figure 6. Data Flow Diagram of Module NORMALIZE

This normalization process differs from that originally devised by Travis. Travis started by sorting the functional dependencies in descending order. This step was determined to be not worth the effort because the only benefit was to simplify the TRANS_DEPEND module somewhat, but it did not seem worth the extra time and effort spent in sorting.

Travis also does not have a module to eliminate dependencies that would result in duplicate relations being created. Numerous other variations have been made to improve the design and will be elaborated upon as they become relevant.

Module NORMALIZE references a global pointer to the relation structure currently being normalized. This makes it easier for each of the sequential modules to work on the relation by avoiding the passing of pointers to pointers on down the line as each module is called.

Module BREAKOUT

Module BREAKOUT performs the first step in the process by traversing the linked list of functional dependencies and separating those dependencies that have multiple dependent attributes into as many new dependencies as there are attributes in the dependent set.

BREAKOUT starts with the first dependency in the list and creates a new functional dependency structure for it. The determinant attribute set is simply linked to the old determinant set rather than recreating those structures for

each attribute in the dependent set. This is more efficient and saves time and space by having only one copy of the determinant set around. Travis' design calls for the creation of a copy of the determinant set for each of the attributes in the dependent set.

BREAKOUT then assigns one of the dependent attributes to the new dependency and then frees that particular attribute from the dependent list. This continues until all dependent attributes have been assigned to a new dependency. BREAKOUT continues down the linked list until all functional dependencies have been broken down into dependencies with a single attribute dependent set.

Module REMOVE SUBS

REMOVE_SUBS is the module that removes those functional dependencies which have subsets of determinant attributes as determinant attributes of other functional dependencies. A key to finding those dependencies with subsets is realizing that only those dependencies with equal dependent attributes need be examined.

The module works by using several pointers to examine the list of functional dependencies. Mainptr is set to the head of the list and Auxptr is used to traverse the list to try to find a dependency with a like dependent attribute. Another pointer, Trailptr, is used to follow Auxptr down the list and is used when it is determined that Auxptr's dependency must be removed. If a dependency is found with a like dependent

attribute, then the check is made to determine if a determinant subset is present, and if one is, which of the dependencies must be removed.

The determination is done by counting the number of attributes in Auxptr's and Mainptr's functional dependencies. Then, the name of each of Mainptr's determinant attributes is compared to every attribute in Auxptr's determinant list, and a count of the number of matches is taken. If the number of matches is equal to the number of attributes of Auxptr's determinant set, then it is Mainptr that should be removed. If the number of matches is equal to the number of attributes in Mainptr's determinant set then Auxptr is removed. If the number of matches does not equal either of those two, then there is no subset present for the pair of dependencies under scrutinization, and Auxptr and Trailptr are advanced down the list to try again. When Auxptr reaches the end of the list, Mainptr is advanced one and Auxptr is reset to point to the dependency one ahead of Mainptr and the process starts again. The procedure ends once Mainptr has traversed the entire list.

Module TRANS_DEPEND

TRANS_DEPEND is the module that searches the functional dependency list for any explicit transitive dependencies that may exist and removes them if present. This module uses four pointers to traverse the list and one trailptr which is used to delete a dependency from the linked list. The four pointers are Mainptr, Single, Aux1, and Aux2. Mainptr is the

pointer that traverses the linked list of functional dependencies searching for the first dependency of a transitive dependency situation. Mainptr is advanced down the list after no transitive dependencies are found or after there are no more transitive dependencies to be removed.

Single is a stationary pointer that points to the first dependency in the list that has a single attribute for it's determinant attribute set. It is used to establish a starting point for Aux1 and Aux2 to start searching for transitivity from. If no single is found, the module returns. The reason for this will become obvious in the next paragraph.

Aux1 starts out pointing to Single and is advanced down the list (stopping only on those functional dependencies that have single attributes in their determinant sets), until the first part of a transitive dependency is found. The reason for considering only dependencies with single attributes in their determinant sets, is that since each dependent attribute set is a single attribute, all multiple determinant attribute sets can be ignored. If Aux1 can not find the first part of a transitive dependency, Mainptr is advanced and Aux1 reset to try again with the new dependency pointed at by Mainptr.

If the first part of a transitivity is found, then Aux2 comes into action. Aux2 like Aux1, starts at Single and traverses the linked list stopping only on dependencies with

single attribute determinant sets. Aux2 tries to find the last part of the functional dependency. If it is found it is deleted, otherwise the explicit transitive dependency does not exist and Auxl is moved one down the list to try again.

Module REGROUP

Module REGROUP consolidates into a single functional dependency all of those dependencies that have identical determinant attribute sets. This consolidation helps to promote one of the main ideas behind databases: eliminating redundancy of data. By regrouping those functional dependencies with identical determinant sets, fewer relations are created in the final step of the process.

REGROUP uses three pointers: Mainptr, Auxptr, and Headptr. Mainptr starts at the head of the list and is advanced down the list when no more dependencies can be regrouped with Mainptr's functional dependency. Auxptr goes down the list one dependency at a time looking for equal determinant sets. If one is found, Auxptr's dependent attribute is added to Mainptr's determinant set. This is done by pointer manipulation rather than creating a new structure for the new dependent attribute. The old dependency is then deleted from the list with the aid of Headptr, which stays one dependency behind Auxptr. This process continues until Mainptr reaches the end of the list.

Module REMOVE DUPL

Module REMOVE_DUPL was not part of Travis' design but was added because like REGROUP, it results in eliminating some data redundancy. Furthermore, it produces a more correct result since it is unlikely that the DBA would want two relations in the database with the exact same attributes in each.

The module again uses three pointers to traverse the list of functional dependencies. Mainptr points to the first dependency and is advanced when all duplicates are removed or none are found. Auxptr moves down the list one dependency at a time, followed by Trailptr, looking for a dependency with the same amount of attributes. If Auxptr finds a dependency with the same number of attributes there is a chance of having a duplicate dependency (as far as the dependency having the same attributes, order is not significant). Having found such a dependency, all of the attributes in Mainptr's dependency are compared to all of the attributes of Auxptr's dependency. If the number of matches is equal to the number of attributes then a duplicate has been found and Auxptr's functional dependency is removed from the list. The procedure continues until Mainptr reaches the end of the list.

Module NEWREL

The final step is to actually create the new relations from the regrouped functional dependencies. It is NEWREL's

job to create a record structure to hold the relation definition and query the DBA to produce a unique name for each new relation. To assist the DBA, a list of the current relations is displayed along with the names of the attributes that will be put into the new relation. The module checks to make sure that the name supplied for the new relation is not a duplicate and then it initializes all values in the relation definition. The initialization will access information that was in the original relation definition, such as domains and security information, as well as setting the NORMALIZE switch for the relation so that the system will not attempt to normalize it again.

After NEWREL creates all of the new relations from the normalization of the old relation, NEWREL prints a copy of the relation to the archive file and then removes the old relation from the linked list of relations. With the completion of NEWREL, control is returned to the NORMALIZE module which in turn returns control to MAIN.

Test Criteria

The family of functional dependencies F which was used to explain the minimal cover technique, was also used to test the normalization software. This test was limited to the normalization software itself and assumes that the procedures developed by Travis perform correctly. While this test case is specific in nature, because it follows Ullman's proven minimal cover technique [9:223], the only "proof" necessary

is to show that the software has been designed and coded correctly, and performs according to Ullman's procedures. Before testing the package as a whole, each module was tested individually, with one module being added and tested at a time. The results of the tests were easy to follow since the software was designed to print the results of each step to the archive file.

Since all cases can not be tested, a specific test was run to ensure that the routines worked correctly for 1 to 3 iterations of the loops inside each module (i.e. multiple transitive dependency elimination), since it seems to be that the biggest problem with modules containing loops that do not perform correctly is that they tend to work for 0, 1 or infinite iterations. As far as loops are concerned, the test designed checks to make sure that the software correctly performs up to 3 iterations. As for the correctness of the results produced, since the minimal cover technique used is fairly simple to follow, it can be done on paper first for any test case and order of functional dependencies, and then run using the normalization system to check the results.

The results of the tests were exactly as expected and paralleled the steps the DBA would perform on paper if he had done the normalization work by hand (see the example in the minimal cover section). Again, the trail left by the normalization software in the archive file was extremely valuable in debugging and checking the correctness of the results.

IV. SPECIFYING FUNCTIONAL DEPENDENCIES

Introduction

A key to any normalization system is the ability for the DBA to specify the functional dependencies that will be used to normalize a relation. Various input methods can be realized and it was decided to investigate the possibilities for their user-friendliness and feasibility in this study. The following sections describe the various methods considered and point out their strengths and weaknesses. After considering the possibilities, two methods were selected, and these methods are described in detail in the next chapter which covers the normalization tool.

Methods for Inputting Functional Dependencies

Regardless of the method used to input functional dependencies, certain criteria must be met. First, and most basically, any automated system to normalize relations is still dependent on the user to supply it with the functional dependencies needed to normalize relations. Since only the user (through the DBA) knows how the data are dependent on each other, there is no way a system can normalize a relation if it is not given the set of functional dependencies that exist because knowledge of the functional dependencies cannot be deduced from the names of the attributes given. Therefore, since the user must interact with the system, the interaction should be made as convenient and simple to

understand as possible.

Second, in order to aid in the interaction, the system should provide the user with a continuous listing of the attributes contained within the relation to be normalized. By doing so, the system helps the user to 'select' the name of an attribute displayed in front of him, rather then having the DBA remember all of the attributes in the relation.

Third, the actual specification of functional dependencies should be as simple and quick as possible. The software should be designed to accommodate the DBA. For example, rather than having the DBA type in an attribute's complete name, let the DBA specify an attribute by typing in a short key number that is displayed alongside each of the attributes.

There are two main methods which can be used to define functional dependencies: to use some device to 'pick' an option, attribute, etc., or to use some device to input the desired option. Traditionally the approach taken was that of making the user input the option desired. This method is simpler to implement but is usually not as user friendly. Making the user type in all responses can be an error prone, tedious process. With the advent of various graphics devices there has been an awakening to the concept of user friendliness. User friendliness means making the tool easy for the user to work with so that the user can concentrate on the work he is trying to accomplish, rather than making the

user concentrate on the tool and the job at the same time. By making the tool so that the user does not have to be a typist to use it, it generally becomes easier to use. In order to accomplish this, many user friendly tools have taken the approach where the user need only select or 'pick' a response or action. This category of tools makes use of state-of-the-art graphics devices such as light pens, mice, touch screens, voice input, digitizer pad input and joysticks. Each of these can be used to develop a tool where the user can select or 'pick' options off of the screen. It should be noted that although keyboard entry was not included in the above options, it too can be used to develop a user friendly tool but it does not lend itself to a 'pick' tool (although one could conceivably be developed using the arrow keys on the keyboard to move around and the return key to signal the selection).

Since the purpose of this study is to develop user friendly tools for the DBA to use, it was decided to employ the selection method over the user input method. The following paragraphs describe some of the various user friendly input methods.

Voice Input. One of the most convenient ways to specify functional dependencies is probably voice input. This essentially frees the DBA's hands for other things. Such a system is certainly feasible and one of the problems with voice input systems (keying on a specific word) would be made

easier by the fact that the DBA could say phrases such as, "Name determines Rank", and the key phrase in every functional dependency would be 'DETERMINES'. The system could display the attributes on the screen for the DBA who could talk his way through the normalization process as if he were thinking aloud. Voice feedback could be added to give instructions as well as tell the DBA what functional dependency he just specified.

Certain problems do remain that make voice input systems expensive and not yet perfected. One big problem is that current technology has not yet solved some of the pattern recognition problems of voice systems. For example, some people pronounce words slightly differently than others and the systems often have to be tailored to one person's speech patterns. Even then, problems exist when a person develops a cold and does not talk as the system expects. As technology improves, this method will certainly be most appealing.

Touch Screen Input. Another relatively new technology that could be used effectively is the touch screen terminal. The system could display the attributes on one screen and instructions on the same screen or another screen, and have the user touch the attributes that belong in a functional dependency. The system would have to prompt the user by asking him to select determinant attributes and after he selected one, ask if there are any more determinant attributes. The same would have to be done with dependent

attributes. To answer the system, the DBA could touch a yes/no box on the screen.

Touch screens seem to be another good input device that allows the user to concentrate solely on the screen. The main drawbacks seem to be making the user press a location on the screen for what he wants, the need to clean the screen often to assure performance, and their relatively high cost.

Mouse Input. There are several ways to use a mouse to input functional dependencies. One way would be to use the mouse to draw a line from attribute to attribute to define the determinant attributes, and then refresh the screen and repeat the procedure for the dependent attributes. This scheme has several inherent problems however. The first problem is the difficulty in figuring out which attribute is being drawn to. The second problem is that the screen can quickly become a cluttered mess if there are many determinant or dependent attributes to draw to.

A better approach would be to use the mouse as a cursor mover for the user to pick out attributes in the determinant and dependent sets. In other words, as the user moves the mouse around its pad, the cursor would be moved correspondingly around the screen. The user could press one of the mouse's keys when he has the cursor positioned over the desired attribute. That attribute would then be selected and highlighted in reverse video. This method is less tricky than drawing but still requires that the user place the

cursor within a relative tolerance distance to the attribute.

In either scenario, the system would require two CRT's to be effective. One screen would be used to prompt the DBA and provide instructions. The other screen would be used to display the attributes and work with the mouse.

The mouse has some benefits and disadvantages as far as user friendliness is concerned. As stated above, the user must get the mouse's position within a specified distance of the target attribute in order to select it. This would seem a drawback to the mouse. Requiring this of the user can make the tool more tedious than it is worth. Unlike touch screen where you concentrate on the screen and 'pick' with the touch of a finger, using the mouse requires the user to concentrate on the screen and the manipulation of the mouse at the same time. The main advantages of the mouse seem to be that it is a cheaper and more available technology.

Light Pen Input. The light pen is another of the 'pick' devices that could be used to input functional dependencies. The system would first prompt the DBA to select determinant attributes. With the light pen, the DBA would pick an attribute after which the system would have to ask the user if there are any more determinant attributes. The DBA would have to answer by either typing his response or possibly using the light pen to pick a response off of the screen. Dependent attributes would be selected in the way after all determinant attributes have been selected.

Keyboard Input. The keyboard entry system is the most conventional method of entry and should not be ignored. It is certainly the least expensive approach and is probably the best understood. Keyboard entry was the approach taken by Travis to input functional dependencies.

The system tells the user that the relation has been selected to be normalized and then instructs him to select determinant attributes first, by typing in their corresponding key number. After each attribute, the system asks the user whether or not there are any more determinant attributes. After all of the determinant attributes have been specified, the process is repeated for the dependent attribute set.

There are a variety of variations in which the user interface could be set up. Perhaps the best is with two screens, one for displaying a full screen of attributes, and the other for instructions and prompts.

Digitizer Pad Input. A digitizer pad could be used in conjunction with a high resolution graphics display as a drawing or sketch pad for the DBA to 'draw' functional dependencies in the same way that the DBA might draw them with paper and pencil when he tries to define the functional dependencies of a relation. For example, the DBA could draw a bubble around the determinant attributes and then draw a line to the dependent attributes. This method is similar to the mouse input method and basically has the same benefits

and weaknesses. While the digitizer pad is more suitable to drawing, the drawing could get very messy quickly. Also, it would be hard to detect which attributes are circled and there is a problem of trying to selectively erase an erroneous line without erasing the entire screen.

Input and Output Enhancements

Regardless of the method used to input functional dependencies, there are several options that can be added for enhancement: color, reverse video, blinking, reordering or indenting attributes that have been selected, and voice feedback. For example, color could be used to color key attributes one color, determinant attributes in another color, and dependent attributes in a third color. Color seems to attract attention to itself and can be used to highlight important objects or the object of current interest. When color is not available, highlighting or reverse video can be used to show the attribute(s) selected. Indenting and/or reordering of attributes can be used in conjunction with any of the other methods in order to offset selected attributes from the rest of the pack. Voice feedback can also be very useful to prompt the user or get his attention, especially when using more than one screen.

Methods Selected

The selection of functional dependency input methods was based on several criteria: availability of the input device,

time available, and usefulness of the device in defining functional dependencies. Of the previously mentioned devices, only the mouse, digitizer pad and keyboard entry are currently available for use in the LSI-11 labs. This cut the selection down to three possible devices. Of these three, two devices, the mouse and digitizer pad, can perform the same basic functions and since it was desired to select 'different' input methods for comparison, it was decided to select only one of these devices. Finally, because of time constraints, the decision was made to implement a functional dependency input method using the mouse.

The second method selected, the keyboard entry system, was selected because it was the method partially implemented by Travis, and a simple method was needed to input functional dependencies in order to test the normalization software developed in this thesis.

The detailed descriptions of these input tools can be found in Chapter 5 which details the workings of the normalization tool interfaces.

V. NORMALIZATION TOOL

Overview

The tool to normalize relations into 3NF consists of two main parts. The first part, the interactive user segment which queries the DBA for functional dependencies, was designed by Travis and completed in this thesis effort. Basically, the interactive user segment provides a method for the DBA to specify functional dependencies of relations to be normalized. The second part is the actual set of routines to do the normalization (discussed in Chapter 3). This part is hidden from the user until the normalization is completed and the user is queried to supply names for the new relations created.

The upper level structure of the normalization tool for the keyboard entry system is shown in Figure 7. The MAIN module calls FILE_OPENER which reads the input file that has been created by Roth's [7] DBMGR program. DBMGR is written in PASCAL and is currently executable only on CPM systems so the data file should be created using DBMGR on a CPM system and then transferred to an RT-11 formatted disk. This file, SETUP.DAT, is then read and searched for the CPM end of file (Control Z) which is subsequently removed along with any trailing garbage in the file. The SETUP.DAT file is not actually modified, instead, the file is rewritten to a file called SETUP2.DAT which is then used to build the linked list structure that holds the relations of the database.

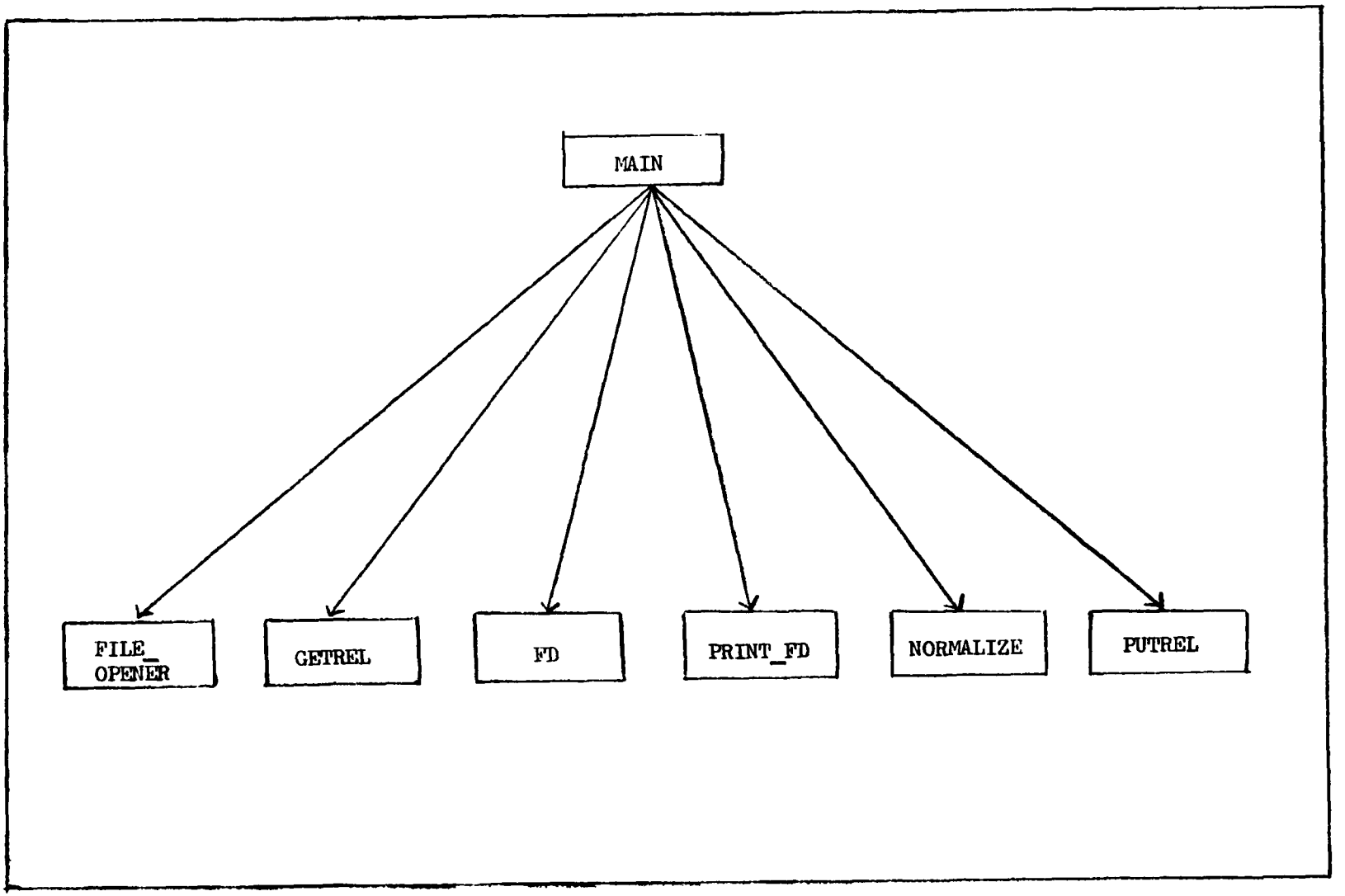


Figure 7. Structure Chart for Normalization Tool

Once the file has been cleaned up, MAIN then calls GETREL which reads the domain definitions from the SETUP2.DAT file and immediately writes them back out to the output file (OUTPUT.DAT). GETREL then reads in the relation definitions and sets up the linked list structure for the relations and their attributes. MAIN then goes down the linked list and finds those relations that are not normalized and that have a zero tuple count (the system can not normalize a relation with data in it). When one is found, FD is called to query the DBA for the functional dependencies that will be used to normalize the relation. FD also sets up the functional dependency structure for the normalize routines to use. Once all of the functional dependencies have been specified, MAIN calls PRINT_FD to print the list of functional dependencies to the archive file for future reference.

The normalization driver routine, NORMALIZE, is then called to perform the actual normalization of the relation in accordance with the functional dependencies specified (details of the normalization process can be found in Chapter 3). Once this has been completed, the old relation is output to the archive file for future reference, and the new relation(s) are inserted into the linked list structure.

MAIN continues this process until all relations have been processed or the DBA exercises his option to quit, in which case the work completed up to that point will be saved in the appropriate files. The final results of the normalization

tool are stored in two files, OUTPUT.DAT and ARCHVE.DAT. OUTPUT.DAT contains the relation definitions for normalized relations. ARCHVE.DAT contains the old relation, the functional dependencies used to normalize it, and the names of the relations created from it.

Defining Functional Dependencies: Screen Input Method

When an unnormalized relation is found (that contains no data, i.e. tuplecount equals zero), MAIN calls the FD module to query the DBA for the functional dependencies that will be needed for the normalization module. The upper level structure chart of FD is shown in Figure 8. When FD is called, the system displays the message to the DBA: "Relation xxxx is selected to be normalized", where xxxx is the name of the relation. This is used to inform the DBA of exactly which relation is being manipulated.

Next, a message is displayed to inform the user that the first step is to define the determinant attribute set (the attributes of functional dependencies on the left hand side). The system follows a sequence of steps that entails listing all of the attributes of the relation, asking the user to choose one as a determinant attribute, and then asking if there are any more determinant attributes to be selected.

To aid the DBA in knowing exactly which attributes are in the relation being normalized, module SHOW_ATTRIBS displays attributes on the screen, four attributes to a line, with 20

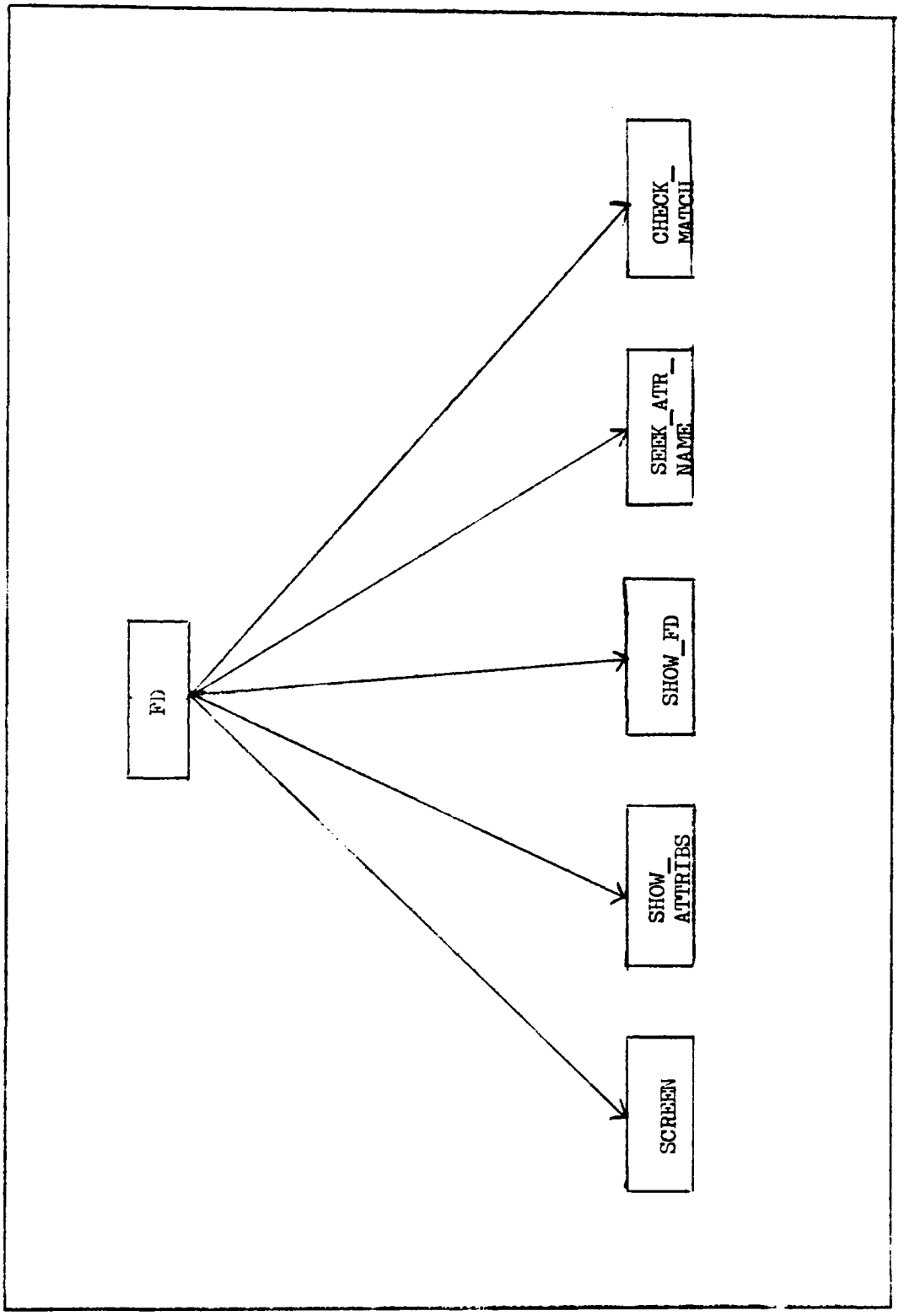


Figure 8. Structure Chart for Module FD

lines of display per screen. If more than 80 attributes exist, module SCREEN is called. SCREEN pauses screen action in order to give the user time to review his options. When the DBA is ready, the DBA can hit any key for a continuation of the listing. Each attribute is displayed with a unique identifying number that allows the DBA to reference each attribute without having to type in the name, by typing in its number instead. By having the DBA type in only the key number of the attribute, the process of specifying functional dependencies is made faster, easier and less prone to typing errors.

When the DBA enters the key number for the attribute he/she wishes to select, the system checks to make sure that it is a valid attribute number. If it is not a valid key number, the system rejects the input and tells the user that the input just made was out of range, try again. When the user inputs a valid key number, FD calls the SEEK_ATR_NAME module to run down the list of the given relation's attributes (find the key number element in the list) and return the name of the attribute selected. The system then displays the name selected to the user to show him the name that was selected (user feedback). The name of the attribute returned is also used to build the functional dependency.

After the DBA inputs a determinant attribute, the system asks if there are any more to determinant attributes to be named. If there are, the attributes are displayed again and

the procedure is repeated. If not, he system proceeds to the naming of the dependent attributes (those on the RHS). As with the determinant attributes, the system sends the user an introductory message, a listing of attributes, a query for the naming of an attribute, and then the question asking the DBA if there are any more dependent attributes to be named.

When the last dependent attribute of the functional dependency is selected, FD calls SHOW_FD to display the functional dependency that was just defined. The DBA is then given a chance to verify that the dependency shown is correct. If the DBA decides that he/she no longer desires the functional dependency or has made a mistake in defining it, the dependency is destroyed. If the DBA verifies the dependency, then module FD calls CHECK_MATCH to make sure the dependency just defined is not a trivial functional dependency (one such as A --> AB, where an attribute on the determinant side also appears on the dependent side of the functional dependency). If a trivial dependency is found, FD writes a message to the user telling him the dependency was trivial and then removes the functional dependency from the linked list. Once it is determined that the functional dependency specified is valid, the system asks the DBA whether or not there are any more functional dependencies to be defined for the current relation. If there are, the process of defining determinant and dependent attribute sets is repeated until all functional dependencies for the current

relation have been defined. Once all the functional dependencies have been defined, control is passed back to MAIN which immediately calls the NORMALIZE module to normalize the relation with respect to the functional dependencies defined for the relation.

Module FD is a self-prompting interactive user-friendly module that has been designed and implemented for consistency. The querying for determinant and dependent attributes are done in a consistent manner. Each section of the module that requests the naming of attributes produces its own queries, accepts the responses and displays error notices in exactly the same manner. By providing similar procedures, consistently, the system helps reduce processing errors and increases speed and ease of use.

Also, after a relation has been normalized, MAIN asks the DBA if he/she wants to continue normalizing relations or end the current session. If the DBA curtails the current session, all of the relations (normalized or not) are written to the output file OUTPUT.DAT with their normalization flags. At a later time, the DBA could rerun the normalization tool using the last output file as the new input file. The DBA could then continue to normalize as many unnormalized relations as desired. This makes the tool more convenient for the DBA to use.

Defining Functional Dependencies: Mouse Input Method

Using the mouse to input functional dependencies differs from the keyboard input method. The upper level structure chart for the mouse input method is shown in Figure 9.

When the mouse input method is used, upon invoking the normalization tool a complete set of instructions is given to the DBA on the first screen and via the Votrax speech synthesizer, informing him/her how to calibrate the mouse and use it to define functional dependencies. Every time the mouse is powered up it must be calibrated to orientate its optics and circuitry to the mouse pad. This can be done easily by moving the mouse diagonally across the mouse pad from the lower left hand corner to the upper right hand corner to the upper right hand corner and then placing it back in its starting corner (bottom left). The mouse initialization routine will assure that the mouse has been calibrated and informs the DBA if it has, or tell the DBA to repeat the process.

When an unnormalized relation is found and the mouse input method is being used, MAIN calls the MOUSE_FD module to query the DBA for the functional dependencies that will be used to normalize the relation. The mouse method, like the keyboard entry method, makes use of two CRTs. One CRT is used to display instructions and prompts to the DBA while the second CRT is used to display the attributes and specify the functional dependencies.

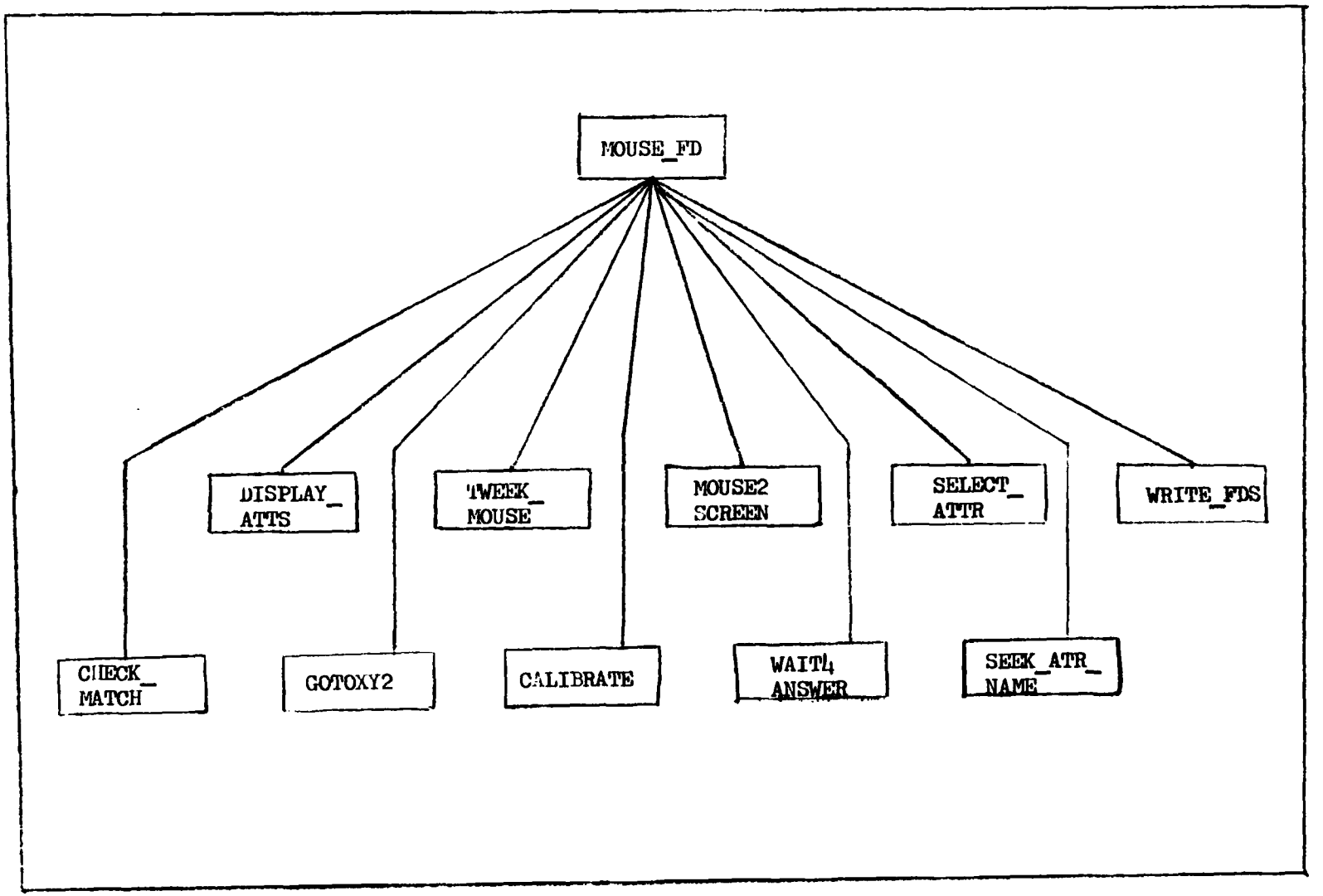


Figure 9. Structure Chart for Module MOUSE_FD

When an unnormalized relation is found, the system displays the message to the DBA: "Relation xxxx is selected to be normalized", where xxxx is the name of the relation. As with the keyboard entry system, this message is used to inform the DBA of exactly which relation is being manipulated.

Next, a message is displayed to inform the DBA that the first step will be to define the determinant attribute set for a functional dependency. The list of attributes are then displayed on the second screen by module DISPLAY_ATTS, with three attributes to a line and a new line every other line, for a total of 24 attributes per screen display. If there are more attributes the DBA can press the right and middle keys of the mouse to get an additional listing. The reason that only 24 attributes are listed per screen in the mouse method (as opposed to 80 in the keyboard entry system), is to make it easier for the DBA to select attributes by moving the mouse. If too many attributes are displayed at once, the screen will become too cluttered for the DBA to be able to manipulate the cursor position via the mouse in order to select an attribute. Also, since attributes would be so close together on the screen, it would require the DBA to move the cursor (via the mouse) within a very fine distance of the desired attribute. In other words, the DBA would have to have painstaking precision in selecting an attribute because if he was off the target by a little bit he could

mistakenly select the wrong attribute. Placing a fair amount of space between attributes makes the selection process easier since the screen is less cluttered (and therefore easier to read) and DBA does not need 'deadly precision with a mouse' in order to succeed.

With the attributes displayed on the second screen, the DBA can now proceed by moving the mouse along the mouse pad (which correspondingly moves the cursor) until he comes upon the desired attribute. The cursor is moved by reading the mouse's coordinates on the mouse pad with module TWEEK_MOUSE. The coordinates are then calibrated by module CALIBRATE and then passed to module MOUSE2SCREEN in order to convert the coordinates into row and column numbers (needed for direct cursor addressing). Finally, module GOTOXY2 is passed the row and column number and performs the direct cursor addressing needed to move the cursor to the corresponding location on the screen.

To select the desired attribute the DBA presses the center key on the mouse which causes MOUSE_FD to call the SELECT_ATTR module. SELECT_ATTR then calculates the number of the attribute selected by the location of the cursor. The SEEK_ATR_NAME module then runs down the list of the given relation's attributes and returns the name of the attribute selected. That attribute is then displayed in reverse video to show the DBA which attribute he selected.

After a determinant attribute has been selected the

system asks the DBA if there are any more determinant attributes to be named. This is done via the first screen and the Votrax (in order to get the DBA's attention). The DBA can answer the system's questions by pressing the left key on the mouse for 'no' and the right key for a 'yes'. Module WAIT4ANSWER waits until there is a change in the status of either the left or right keys. If there are more determinant attributes to be specified, the attributes are displayed again and the process is repeated.

When all of the determinant attributes for a functional dependency have been specified the system proceeds to the naming of the dependent attributes. The procedure is exactly the same as with the determinant set except for the system message telling the DBA to select dependent attributes.

After the last dependent attribute of the functional dependency has been specified, the system calls SHOW_FD to display the functional dependency that was just defined. This gives the DBA an opportunity to verify that the dependency shown is correct, by pressing the right key of the mouse to answer yes or the left key to answer no. If the DBA decides that he/she no longer desires the dependency or has made a mistake in defining it, the dependency is destroyed. If the DBA verifies the functional dependency, the system then calls CHECK_MATCH to make sure the functional dependency just specified was not trivial, and removes it if it was. Then the system asks the DBA (via the first screen and the

Votrax) if there are any more functional dependencies to be defined for the current relation. If there are, the process of defining determinant and dependent attributes is repeated until all functional dependencies for the current relation have been defined. Once all functional dependencies have been defined, module WRITE_FDS is called to write the functional dependencies to a file (FDFILE.DAT). When all functional dependencies have been defined for all of the relations the DBA wishes to normalize, control is returned to MAIN which then closes files and completes execution.

To normalize the relations when the mouse method is used, it is necessary to run a second program (P2NORM) which reads in the relations and their functional dependencies, recreates their linked-list structures, and then calls the NORMALIZE module to normalize the unnormalized relations with respect to the functional dependencies that have been defined. As with the keyboard entry method, the DBA is required to type in the names for the newly created relations.

It was necessary to divide up the program to define functional dependencies with the mouse and normalize the relations into two parts because of the size of the code and the memory limits of the LSI-11 systems. Program P2NORM contains the modules to perform the normalization and functions exactly like the normalization tool used with the screen input method, creating the same results and files.

VI. TESTING, CONCLUSIONS AND RECOMMENDATIONS

Testing

The Normalization system was tested using both the keyboard entry method and the mouse method for defining functional dependencies. Several students that had taken the database courses here at AFIT volunteered to try both methods and answer questions concerning user-friendliness, ease-of-use, and preference of tool (mouse or keyboard). On a scale of 1-5 (with one being excellent and five being unacceptable), user-friendliness received an average score of 2.2 for the keyboard method and 1.4 for the mouse method. Ease-of-use received average scores of 2.0 and 1.8. There was no clear preference of tool, about half of the people preferred the mouse method, the other half the keyboard entry method.

In less than a half hour, the students were able to learn how to use both of the input methods, successfully define functional dependencies, and subsequently normalize relations without much difficulty. Most of the criticism dealt with the speech quality of the Votrax, the somewhat laborous mouse calibration procedure, and a few minor details concerning the screen displays.

Conclusions

The goals of this thesis effort were to investigate the tasks of the DBA and outline those areas where computer aided tools would be most useful. Once this was established,

twenty-one tools were described and a selection process was devised to select those tools to be implemented in this thesis. The normalization tool selected was a completion of the work started by Travis [6] and is integrated with the standards of the database created by Roth [7].

With the initial research completed and the tools for implementation selected, the effort of this thesis was divided into two main areas of design, implementation and testing: the front ends to the normalization tool which allow the DBA to specify functional dependencies, and the part to do the actual normalization of relations to 3NF. While still in the analysis stage of Travis' design it was determined that the entire system should be moved from the UCSD PASCAL used by Travis to Whitesmith 'C' in order to avoid the problems encountered by Travis [6:69]. This involved rewriting and redesigning Travis' code to run under Whitesmith 'C'. During the process, several errors in the original design were corrected and numerous improvements were made to take advantage of the 'C' language and the H-29 terminal's capabilities. One design flaw corrected in the early stages was the addition of a module to eliminate any trivial functional dependencies specified (since they are not used to normalize a relation and would not have been removed by the other modules of the normalization system).

After Travis' work was recaptured, with the FD screen method for entering functional dependencies working, the next

step was to implement the normalization process from Travis' pseudo code. After careful analysis of Travis' design it was determined that the design was incomplete. In order to complete the design several changes were made. First, the module to sort functional dependencies was deemed a waste of time and effort since it only served to simplify the coding of the module that searches for transitive dependencies. Second, a module to remove dependencies that have exactly the same attributes was added (after the 'normalization' process but before the new relations were created) to prevent the creation of more than one relation with exactly the same attributes in each relation, since creation of duplicate relations is likely to defeat the purpose of database management. Also added were modules to write to a file the original relation, the functional dependencies used to normalize it, and the names of the new relations created. These routines provide an excellent way of maintaining a record of the manipulated relations.

After the normalization modules were implemented and tested the focus of the study turned to designing a new interface for the normalization tool that uses a mouse as the input device. The design and implementation of the basic modules to allow the user to select attributes from the screen (as opposed to typing in their key numbers) was designed and implemented to a working stage. Future effort should be directed at putting the finishing touches on the

implementation to make the mouse input front-end a more complete user friendly tool.

Recommendations

This thesis effort, by investigating the tasks of the DBA, detailed areas where computer aided tools could be used to assist the DBA. Future thesis efforts could certainly design and implement some or all of the twenty-one tools that were described in Chapter 2. Another area that deserves attention is the investigation, design and implementation of a system to carry the normalization process up to 5NF. This would be a challenging thesis for someone interested in databases because, at the time of this thesis, there were no published algorithms to perform the normalization to 5NF. Furthermore, normalizing relations past 3NF can produce undesirable relations. The challenges would include coming up with the algorithms and determining when a relation should be carried out to 5NF. Also, a utility could be added to the normalization routines to handle the case of disjoint functional dependency sets (where all of a relation's attributes are not used).

The design and implementation of other front-ends to the normalization tool is another fruitful area in the user friendly design area. The front-ends suggested in Chapter 4 or any variations of the existing front-ends could be implemented and then comparison tested by having an AFIT database class work with each of the front-ends.

BIBLIOGRAPHY

1. Allred, Dean, "Consolidated AFIT Database," (Thesis) School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1980.

2. David W. Taylor Naval Ship research and Development Center. Information Systems Design Methodology: Global Logical Data Base Design. Bethesda Md. Aug 1982.

3. Cleveland Cadonics User's Manual. Cleveland Cadonics Inc., 1982.

4. Date, C. J., An Introduction to Database Systems. (Third Edition) Massachusetts: Addison-Wesley Publishing Company, 1982.

5. Hubbard, George. Computer Assisted Database Design. New York: Van Nostrand Reihnhold Company, 1981.

6. Travis, Charles, "Interactive Automated System for Normalization of Relations," (Thesis) School of Engineering, Air Force Institute of Technology, Wright-Patterson AFB, Ohio, 1983.

7. Roth, Mark A., "The Design and Implementation of a Pedagogical Relational Database System," (Thesis) School of Engineering, Air Force Institute of Technology, Wright Patterson AFB, Ohio, 1979.

8. Summamouse Technical Reference. Summagraphics Corporation Publlication 84-DSM1-830. Fairfield, Conn. August, 1983.

9. Ullman, jeffrey D., Principles of Database Systems. (Second Edition) Maryland: Computer Science Press, 1982.

10. Vetter, M. and Maddison, R., Database Design Methodology. New Jersey: Prentice Hall, 1981.

11. Votrax Type N Talk User's Manual. Votrax Division of Federal Srew Works, Troy Michigan, 1981.

12. Weldon, Jay-Louise. Database Administration. New York: Plenum Press, 1981.

13. Wilson, Max. "A Requirements and Design Aid for Relational Databases," IEEE SOFTE. 1981: p.283-293.

APPENDIX A

User's Guide To The AFIT Relational Database System Relation Normalization Facility

Introduction and Overview

The Relation Normalization Facility described in this document is a program to provide the Database Administrator (DBA) with the ability to normalize relations to Third Normal Form (3NF). This facility contains two different front ends that the DBA can use to interact with the program. The first method is designed to be used primarily with the use of two CRT terminals and a keyboard, and is written in Whitesmith 'C'. The second method for inputting functional dependencies is also designed to be used with two CRT terminals and is written in Whitesmith 'C', but in uses a Summamouse to define the functional dependencies. The Normalization facility is intended to be run on the LSI-11 microcomputers of the AFIT Digital Engineering Lab under control of the RT-11 operating system, version 4.0

The tool to normalize relations into 3NF consists of two main parts. The first part, the interactive user segment which queries the DBA for functional dependencies, was designed by Travis and completed in this thesis effort. Basically, the interactive user segment provides a method for the DBA to specify functional dependencies of relations to be normalized. The second part is the actual set of routines to do the normalization (discussed in Chapter 3). This part is

hidden from the user until the normalization is completed and the user is queried to supply names for the new relations created.

The upper level structure of the relation normalization facility for the keyboard entry method is shown in Figure 10. MAIN calls FILE_OPENER to open the input and output files as well as calling the GETREL, FD, PRINTFD, NORMALIZE and PUTREL modules when appropriate to do so.

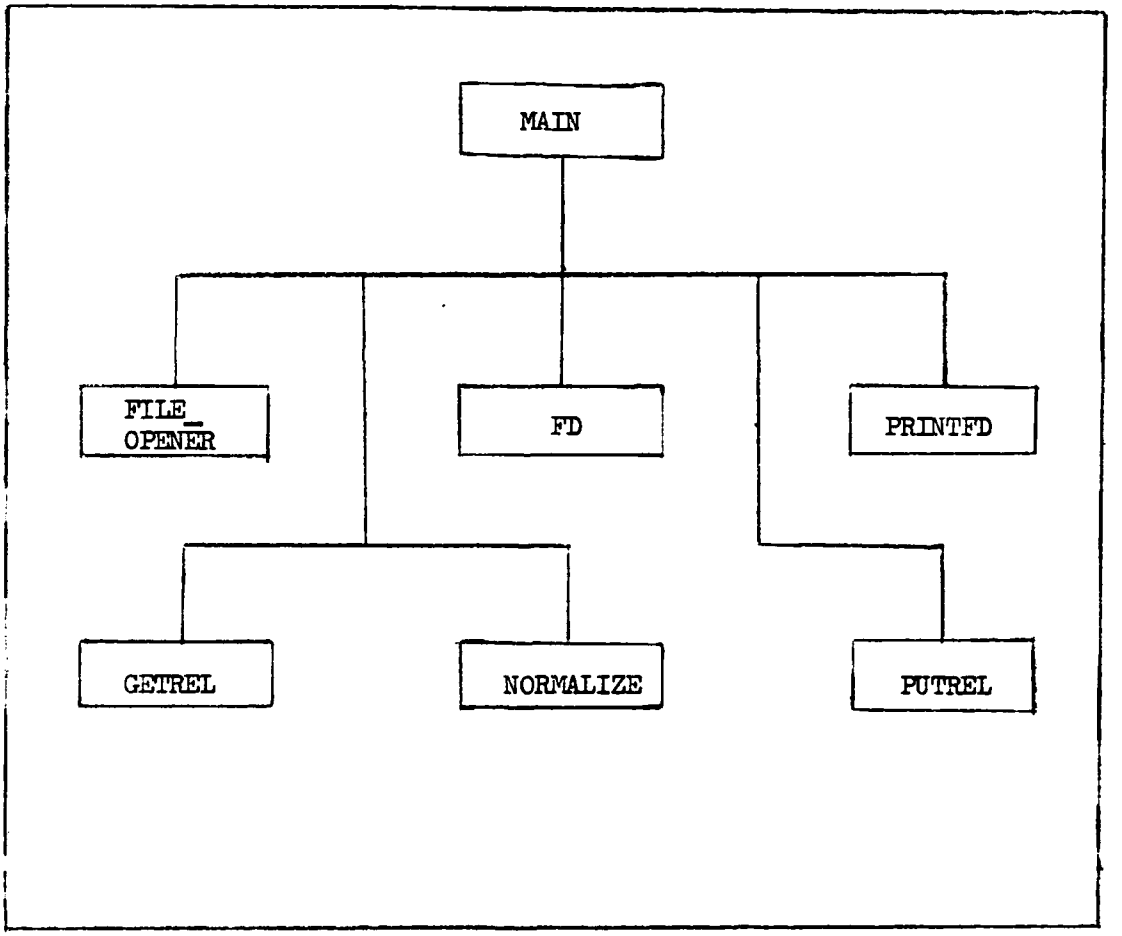


Figure 10 Structure Chart For Normalization Facility

How to Use the Relational Normalization Facility: Keyboard Entry Method.

To start the system, execute the file NORM on the disk marked 'Keyboard Fd Entry Method'. The system disk must be a Whitesmith 'C' disk and the data disk must contain the data file containing the relation definitions and the NORM program. When the system is run, MAIN calls FILE_OPENER which reads the input file that has been created by Roth's [7] DBMGR program. DBMGR is written in Pascal and is currently executable only on CPM systems so the data file should be created using DBMGR on a CPM based system and then transferred to an RT-11 formatted disk. This file, SETUP.DAT, is then read and searched for the CPM end of file (Control Z) which is subsequently removed along with any trailing garbage in the file. The SETUP.DAT file is not actually modified, instead, the file is rewritten to a file called SETUP2.DAT which is then used to build the linked list structure that holds the relations of the database.

Once the file has been cleaned up, MAIN then calls GETREL which reads the domain definitions from the SETUP2.DAT file and immediately writes them back out to the output file (OUTPUT.DAT). GETREL then reads in the relation definitions and sets up the linked list structure for the relations and their attributes. MAIN then goes down the linked list and finds those relations that are not normalized and that have a zero tuple count (the system can not normalize a relation

with data in it). When one is found, FD is called to query the DBA for the functional dependencies that will be used to normalize the relation. FD also sets up the functional dependency structure for the normalize routines to use. Once all of the functional dependencies have been specified, MAIN calls PRINT_FD to print the list of functional dependencies to the archive file for future reference.

The normalization driver routine, NORMALIZE, is then called to perform the actual normalization of the relation in accordance with the functional dependencies specified (details of the normalization process can be found in Chapter 3). Once this has been completed, the old relation is output to the archive file for future reference, and the new relation(s) are inserted into the linked list structure.

MAIN continues this process until all relations have been processed or the DBA exercises his option to quit, in which case the work completed up to that point will be saved in the appropriate files. The final results of the normalization tool are stored in two files, OUTPUT.DAT and ARCHVE.DAT. OUTPUT.DAT contains the relation definitions for the normalized relations. ARCHVE.DAT contains the old relation, the functional dependencies used to normalize it, and the names of the relations created from it.

Defining Functional Dependencies: Keyboard Input Method

When an unnormalized relation is found (that contains no data, i.e. tuplecount equals zero and normalize flag set to

false), MAIN calls the FD module to query the DBA for the functional dependencies that will be needed for the normalization module. When FD is called, the system displays the message to the DBA:

"Relation xxxx is selected to be normalized", where xxxx is the name of the relation. This is used to inform the DBA of exactly which relation is being manipulated.

Next, a message is displayed to inform the user that the first step is to define the determinant attribute set (the attributes of functional dependencies on the left hand side). The system follows a sequence of steps that entails listing all of the attributes of the relation, asking the user to choose one as a determinant attribute, and then asking if there are any more determinant attributes to be selected.

To aid the DBA in knowing exactly which attributes are in the relation being normalized, the attributes are displayed on the screen four attributes to a line, with 20 lines of display per screen. If more than 80 attributes exist the listing is stopped temporarily when the screen is full in order to give the DBA a chance to review the attributes. When the DBA is ready, the DBA can hit any key for a continuation of the listing. Each attribute is displayed with a unique identifying number that allows the DBA to reference each attribute without having to type in the name, by typing in it's number instead followed by a <CR>. By

having the DBA type in only the key number of the attribute, the process of specifying functional dependencies is made faster, easier and less prone to typing errors.

When the DBA enters the key number for the attribute he wishes to select, the system checks to make sure that it is a valid attribute number. If it is not a valid key number, the system rejects the input and tells the user that the input just made was out of range, try again. When the DBA inputs a valid key number, the system will find that attribute and then display the name selected to the user to show her/him the name that was selected (user feedback). The name of the attribute returned is also used to build the functional dependency.

After the DBA inputs a determinant attribute, the system asks if there are any more to determinant attributes to be named. If there are, the DBA types in a 'Y' or 'y', causing the attributes to be displayed again, and then the process of specifying a determinant attribute is repeated. If not, the DBA types any other character (unless otherwise stated, when a yes/no answer is required, any key pressed other than a 'Y' or 'y' is considered to be a no answer) and the system proceeds on to the naming of the dependent attributes (those on the RHS). As with the determinant attributes, the system sends the user an introductory message, a listing of attributes, a query for the naming of an attribute, and then the question asking if there are any more dependent

attributes to be named.

When the last dependent attribute of the functional dependency is selected, FD displays the functional dependency that was just defined. The DBA is then given a chance a to verify that the dependency shown is correct. If the DBA decides that he/she no longer desires the functional dependency or has made a mistake in defining it, the dependency is destroyed. If the DBA verifies the dependency be typing in a 'y' or 'Y', then FD makes sure the dependency just defined is not a trivial functional dependency (one such as A --> AB, where an attribute on the determinant side also appears on the dependent side of the functional dependency). If a trivial dependency is found, FD writes a message to the user telling him the dependency was trivial and then removes the functional dependency from the linked list. Once it is determined that the functional dependency specified is valid, the system asks the DBA whether or not there are any more functional dependencies to be defined for the current relation. If there are, the process of defining determinant and dependent attribute sets is repeated until all functional dependencies for the current relation have been defined. Once all the functional dependencies have been defined, control is passed back to MAIN which immediately calls the NORMALIZE module to normalize the relation with respect to the functional dependencies defined for the relation.

Also, after a relation has been normalized, the system asks the DBA if he wants to continue normalizing relations or end the current session. If the DBA curtails the current session, all of the relations (normalized or not) are written to the output file OUTPUT.DAT. At a later time, the DBA could rerun the normalization tool using the last output file as the new input file. The DBA could then continue to normalize as many unnormalized relations as he wants or has time for. This makes the tool more convenient for the DBA to use.

How to Use the Relational Normalization Facility: Mouse Input Method.

Because of the size of the code, the Mouse Input Method is divided up into two separate programs, P1NORM and P2NORM. P1NORM is the program in which the functional dependencies are defined with the mouse and P2NORM reads the functional dependencies and does the actual normalization of the relations.

To start the system, execute the file P1NORM on the disk marked 'Mouse Fd Entry Method'. The system disk must be a Whitesmith 'C' disk and the data disk must contain the data file containing the relation definitions and the P1NORM and P2NORM programs. When the system is run, MAIN calls FILE_OPENER which reads the input file that has been created by Roth's [7] DBMGR program. DBMGR is written in Pascal and is currently executable only on CPM systems so the data file

should be created using DBMGR on a CPM based system and then transferred to an RT-11 formatted disk. This file, SETUP.DAT, is then read and searched for the CPM end of file (Control Z) which is subsequently removed along with any trailing garbage in the file. The SETUP.DAT file is not actually modified, instead, the file is rewritten to a file called SETUP2.DAT which is then used to build the linked list structure that holds the relations of the database.

Once the file has been cleaned up, MAIN then calls GETREL which reads the domain definitions from the SETUP2.DAT file and immediately writes them back out to the output file (OUTPUT.DAT). GETREL then reads in the relation definitions and sets up the linked list structure for the relations and their attributes. MAIN then calls MOWSE_UP to give the DBA instructions on how to get the mouse ready for use and how to use it to define functional dependencies.

When the DBA has calibrated the mouse, MAIN goes down the linked list and finds those relations that are not normalized and that have a zero tuple count (the system can not normalize a relation with data in it). When one is found, MOUSE_FD is called to query the DBA for the functional dependencies that will be used to normalize the relation. Once all of the functional dependencies of a relation have been specified, MAIN calls WRITE_FD to write the list of functional dependencies to the FDFILE.DAT file for use by P2NORM.

DBA to repeat the process again if the mouse has not been properly calibrated.

When an unnormalized relation is found and the mouse input method is being used, MAIN calls the MOUSE_FD module to query the DBA for the functional dependencies that will be used to normalize the relation. The mouse method, like the keyboard entry method, makes use of two CRTs. One CRT is used to display instructions and prompts to the DBA while the second CRT is used to display the attributes and specify the functional dependencies.

When an unnormalized relation is found, the system displays the message to the DBA: "Relation xxxx is selected to be normalized", where xxxx is the name of the relation. As with the keyboard entry system, this message is used to inform the DBA of exactly which relation is being manipulated.

Next, a message is displayed to inform the DBA that the first step will be to define the determinant attribute set for a functional dependency. The list of attributes are then displayed on the second screen, three attributes to a line and a new line every other line, for a total of 24 attributes per screen display. If there are more attributes the DBA can press the middle key of the mouse to get an additional listing. The reason that only 24 attributes are listed per screen in the mouse method (as opposed to 80 in the keyboard entry system), is to make it easier for the DBA to select

MAIN continues this process until all relations have been processed or the DBA exercises his option to quit, in which case the work completed up to that point will be saved in the appropriate files. The final results of the P1NORM are stored in FDFILE.DAT.

Defining Functional Dependencies: Mouse Input Method

Using the mouse to input functional dependencies differs from the screen input method. When the mouse input method is used, upon invoking the normalization tool a complete set of instructions is given to the DBA on the first screen and via the Votrax speech synthesizer, informing him how to calibrate the mouse and use it to define functional dependencies. Every time the mouse is powered up it must be calibrated to orientate it's optics and circuitry to the mouse pad. This can be done easily by moving the mouse diagonally across the mouse pad from the lower left hand corner to the upper right hand corner and then placing it back in it's starting corner (bottom left).

The DBA is then required to 'zero out' the mouse's coordinates (make sure the origin is set at 0,0) by picking the mouse up and placing it in the upper right hand corner and then sliding it down along the diagonal to the bottom left hand corner. This must be done three times to insure correct results.

The mouse initialization routine will assure that the mouse has been calibrated and inform the DBA if it has, or tell the

attributes by moving the mouse. If too many attributes are displayed at once, the screen will become too cluttered for the DBA to be able to manipulate the cursor position via the mouse in order to select an attribute.

With the attributes displayed on the second screen, the DBA can now proceed by moving the mouse along the mouse pad (which correspondingly moves the cursor) until he comes upon the desired attribute. When moving the mouse it is important to keep it on the pad at all times.

To select the desired attribute the DBA presses the center key on the mouse which causes the selected attribute to be displayed in reverse video in order to show the DBA which attribute he/she selected.

After a determinant attribute has been selected the system asks the DBA if there are any more determinant attributes to be named. This is done via the first screen and the Votrax (in order to get the DBA's attention). The DBA can answer the system's questions by pressing the left key on the mouse for 'no' and the right key for a 'yes'. The system will wait until there is a change in the status of either the left or right keys. If there are more determinant attributes to be specified, the attributes are displayed again and the process is repeated.

When all of the determinant attributes for a functional dependency have been specified the system proceeds to the naming of the dependent attributes. The procedure is exactly

the same as with the determinant set except for the system message (via the first screen and Votrax) telling the DBA to select dependent attributes.

After the last dependent attribute of the functional dependency has been specified, the system displays the functional dependency just defined on the first screen. The DBA is then given a chance to verify that the dependency shown is correct. If the DBA decides that he/she no longer desires the functional dependency or has made a mistake in defining it, he/she presses the left key on the mouse and the dependency is destroyed. If the DBA verifies the dependency by pressing the right key on the mouse, the system proceeds to check that the functional dependency specified was not trivial and removes it if it is. Then the system asks the DBA (via the first screen and the Votrax) if there any more functional dependencies to be defined for the current relation. If there are, the DBA presses the right key on the mouse and the process of defining determinant and dependent attributes is repeated until all functional dependencies for the current relation have been defined. Once all functional dependencies have been defined, module WRITE_FDS is called to write the functional dependencies to a file (FDFILE.DAT). When all functional dependencies have been defined for all of the relations the DBA wishes to normalize, control is returned to MAIN which then closes files and completes execution. To normalize the relations when the mouse method

is used, it is necessary to run a second program (P2NORM) which reads in the relations and their functional dependencies, recreates their linked-list structures, and then calls the NORMALIZE module to normalize the unnormalized relations with respect to the functional dependencies that have been defined.

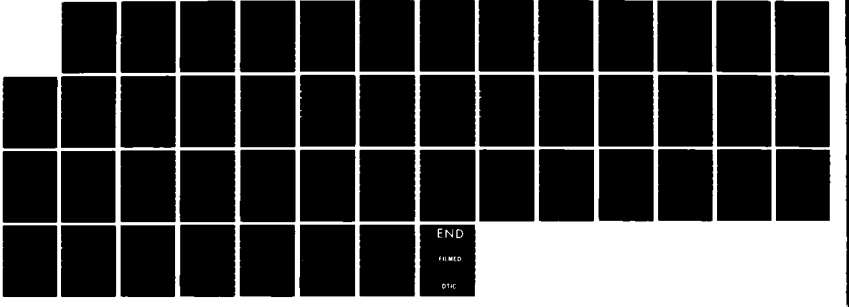
It was necessary to divide up the program to define functional dependencies with the mouse and normalize the relations, into two parts because of the size of the code and the memory limits of the LSI-11 systems. Program P2NORM contains the modules to perform the normalization and functions exactly like the normalization tool used with the screen input method, creating the same results and files.

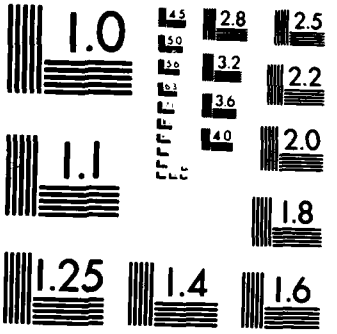
Normalizing Relations

After the functional dependencies for an unnormalized relation have been defined the normalization process is automatically called when the keyboard input method is used and must be run using P2NORM when the mouse input method is used. The normalization process itself is transparent to the DBA until the very end when the new relations are actually created. At this point the system displays the list of current relations names on the second screen along with the attributes that make up each of the new relation(s) and asks the DBA to input a name for each of the newly created relation(s) (one relation at a time). The name must be 25 characters or less with no blank spaces in the name.

AD-A151 782 DEVELOPMENT OF COMPUTER AIDED DATABASE DESIGN AND MAINTENANCE TOOLS(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGINEERING 2/2

UNCLASSIFIED E R JANKUS DEC 84 AFIT/GCS/EE/84D-10 F/G 9/2 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX B

Development of Computer Aided Database Design and Maintenance Tools

Introduction

The design, development and maintenance of a database can be a very time-consuming and complex task. One of the many responsibilities of the database administrator (DBA) is to make sure that the database performs efficiently and consistently, with data integrity and limited data redundancy. A key to this is to ensure that the database is properly set up.

A relational database consists of tables(relations) which themselves consist of unordered sets of entries. Each of these entries is a meaningful collection of related information about the objects around which the relation was composed. Each table entry is called a tuple (row). Tuples are themselves composed of fields called attributes (columns).

In order for a database to perform with any merit, certain design constraints must be built into the system. Normalization theory, a useful aid in the database design process, is based on the concept of normal forms. A relation is said to be in a particular normal form if it satisfies a certain specified set of constraints.

There are numerous normal forms and generally the

'higher' the normal form of a relation, the better. In other words, 3NF is more desirable than 2NF, which is more desirable than 1NF. This is so because the higher normal forms remove more of the undesirable properties that lead to the insertion/deletion anomalies that cause data inconsistency and loss of data integrity.

Normalization of relations is only one of the DBA's tasks that can be enhanced through the use of computer aided design (CAD) tools. CAD tools are user-friendly interactive programs that often simulate the behavior of some system or task to the display console operator for further interactive design and testing. For example, CAD programs have been used extensively to design computer chips. Through interaction with the program, the user designs the chip layout and subsequently tests it on a simulator (another CAD tool) to determine if it works. The user can then go back and make any desired changes in the layout any number of times before a prototype is ever built. Such a procedure saves time and money and is used in many applications.

While a database is not a physical entity like a chip, it too requires design layout and testing. It would therefore seem reasonable to try to create some CAD tools for the DBA to use to handle his or her complex and time consuming tasks faster, easier and more effectively.

Problem

The purpose of this effort was to solve two problems. First, since the DBA has many tasks that must be performed, any time saved on any of the tasks is beneficial. Normalization is but one of the major tasks facing the DBA. The problem with normalization is that getting relations into the desired normal form is not always a trivial task. Like an art, it often takes much time and does not present an obvious answer. Obscure data dependencies may get past the DBA and foul the system.

The second problem is to define the various tasks of the DBA in the design, development and maintenance of a database, and determine what other tasks can be improved through the use of CAD tools. Hence, this study should have direct application in the rapidly expanding database area.

Scope

The requirements analysis of the DBA's tasks was performed to identify those areas where CAD tools could be used. From the outcome of this search it was determined that two tools would be implemented in this thesis.

The first tool is a tool to normalize unnormalized relations into Third Normal Form. This entails completing the work started by Travis in this area, and carrying it out to generate up to 3NF.

The second tool selected compliments the normalization tool. It is a completely redesigned user friendly front end

for the normalization tool that uses a mouse to make it easier for the DBA to input functional dependencies.

Approach

In order to accomplish this study, first an in-depth literature review was undertaken to explore other current efforts in computer aided database design, and to find those areas of the DBA's tasks that would benefit most from computer aided tools. Very little work has been recorded in these areas. With the literature review completed, the next step was to detail the findings and select the tools to be implemented.

The focus of the study then turned to implementing the normalization tool. The first step was to examine the design and code already written by Travis [6], to determine how it works and to complete the design. Taking a top-down structured approach, and using various graphics and user interface concepts, the remaining modules were coded and tested until they worked for 3NF.

Once the normalization tool was completed, the attention of the study was directed towards interfacing the mouse to the LSI-11 system and designing the interface to use the mouse to input the functional dependencies used in the normalization process. This interface was designed in a top-down structured fashion and implemented.

Sequence of Presentation

The remainder of this paper will discuss some of the various tasks of the DBA and present 21 computer aided tools that can be used to assist the DBA in performing those tasks. The normalization tool and the two interfaces that were developed to allow the DBA to specify functional dependencies for the normalization tool are also detailed. Finally, recommendations for future work on computer aided database design are presented at the end of this paper.

Designing Tools for the DBA

Before designing tools for the database administrator to use, it is necessary to answer the somewhat nebulous question, "what are the tasks of the database administrator?". To answer this question several interviews and a literature search were performed. A good overview of the DBA's duties was found in the text by Weldon [12], and includes among other things, the following suggestions:

Database Planning Phase:

1. Define database goals in support of organizational goals.
2. Develop and revise plans to achieve database goals, in particular, plan the transition to the database environment.
3. Assess the impact of changes in technology and information requirements on the database.
4. Evaluate and select hardware and software to be used to support database operations.

Database Design Phase:

5. Control the database design process through the integration of data needs and the scheduling of application development.

6. Provide expertise on methods for requirements analysis, database design and on the DBMS.

7. Make decisions concerning design trade-offs.

8. Guide and consolidate logical database design, and provide expertise in data modeling, defining data, and integrating user's views.

9. Perform the physical design of the database, and select storage and access methods.

10. Maintain a physical data description or data dictionary.

Database Operation and Control:

11. Set and enforce data standards for data definition, application coding, testing and system design.

12. Develop and install procedures for error detection and resolution.

13. Set policies for database backup and recovery.

14. Establish and enforce a comprehensive database security policy that includes user authorization, internal controls, and controls on personnel.

15. Develop and monitor database performance indicators.

16. Resolve database operational problems through fine tuning, reorganization, or redesign.

17. Maintain the DBMS and related software.

Database Usage:

18. Build, maintain, and distribute information about the database to users, operators, and system developers.

19. Select the data dictionary package to be used.

20. Define and enforce standards for data naming, coding,

documentation, and system development procedures [12:12-13].

Database Design

The design of a database remains somewhat a black art, often marked by the use of ad hoc methods of design. These ad hoc methods often create a product that falls short of the target. The reason is that there are many things to be considered when designing a database and ad hoc methods rarely take all things into consideration. What is needed is a more systematic and structured approach to database design, one that lends itself to the use of computer aided design tools.

The DBA faces several major problems when designing a database. First, he must determine the data requirements, i.e., the portion of the 'world' to be represented. As with any major software development project, finding out what the users really need/want is one of the most difficult tasks, for often the user himself is unsure of what he really wants. Secondly, the DBA must consolidate the requirements of several applications or departments into a unified set for shared use. Third, the DBA must design for the future, that is, anticipate changes in usage and design so that changes in the system can be made without an entire redesign.

Once the data requirements are established, they must be mapped into the logical data model and the physical storage structures that are supported by the DBMS. Regardless of the DBMS used, the database design should follow the basic

standards of database design in order to minimize data redundancy, avoid insertion and deletion anomalies, provide adequate performance, and provide for ease in design changes [13:283].

As a practical consideration, the structured iterative approach is usually not feasible by using purely manual design techniques. Such a methodology is desireable however, because it can provide a significant quality control capability to the design process [5:23]. For these reasons, all of the computer aided design tools discussed will be useful in achieving such a structured iterative design.

Computer Aided Design Tools

Research and interviews into the idea of using computer aided design tools to assist the DBA revealed several good design methodologies which in themselves provide opportunity for computer aids. Many of the ideas found deal with providing the DBA with some sort of report to assist him in design trade-offs, finding errors in design, and increasing design efficiency while at the same time reducing design time.

The following is a list of potential design tools discovered through interviews and an extensive literature review:

For use in general database design:

1. One aid to database design would be a tool to help the DBA determine the functional specifications that the end user desires. By producing exact formats of the desired screens and reports, computer aids can help end users

see how well the report will meet their needs. Experience also indicates that when this type of approach is used, the data requirements are less likely to change during the design process [5:24].

2. When integrating the various user's views, an alphabetical list of names along with where they are used, and a list showing the contexts in which all the qualifications of the data names are used, would be helpful in finding synonyms, homonyms, and other naming inconsistencies. It could also be used to detect problems and inconsistencies in usage, format and meaning of the data item in the various local views [5:47].

3. An 'intersecting data elements report' containing a list of all data elements having more than one key. Such a list could be used to help identify naming inconsistencies and redundant data [5:96].

4. A data element usage matrix showing which data elements are used by which functions [5:97]. This matrix is more or less a condensed form of the list of #2, in a somewhat graphical representation.

5. An interactive graphics display for the cononical design technique. It could draw the graphs and list the attributes and relations as the entities were added to the graph. The graph defines the records with their keys and attributes and shows the associations between the records [1:65].

6. Use of PSL/PSA to analyze requirements, design the global logical database, define the database process, design the physical database, and simulate database operation [2].

7. A tool to assist the DBA in conveniently meshing individual subschemas or views together into the global logical model. Naming and other inconsistencies would have to be resolved by the DBA, perhaps interactively with the use of some of the forementioned design reports [10:73].

8. A local view report that gives the contributions of each local view in the final logical view derived. This report could be useful to a DBA who wants to evaluate the effect of an application on the overall design [5:97].

9. Physical design tools. An on line system for the designer to make and specify physical design choices and options. A conversational terminal session can guide the designer in selecting device type, access methods, block size, secondary data set groups, pointer options,

and ordering choices [5:135-136].

Tools for relational database design:

10. A list of the transitive dependencies identified and removed from the design. This could be useful to the designer who may want to reinsert some of the dependencies, at the expense of redundancy, in order to gain performance and validity benefits [5:95].

11. A list of functional dependencies removed to obtain functional dependence. This could be used by the DBA to reinsert a dependency if it is important to the way the organization functions. At a cost of increased data redundancy, it may be better to have the dependency exist for performance reasons, or to more accurately or conveniently represent the organization's requirements as they really are [5:128].

12. Identification of domains. A list of domains represented by the data elements, and of which elements (key or attribute) belong to which domain. The primary use of this would be for determining the potential for natural joins between derived relations [5:122].

13. Produce performance weights and relation sizes to assist the designer with efficiency considerations such as:
    a) frequency of use of individual relations
    b) frequency of use of the attributes within a relation
    c) frequency of need for joins [5:125-126].

14. A derived relations report showing the most frequently derived relations [5:127]. If the need for space-and-time costly joins is too great, it may be desirable to create an extra view to contain that information that is derived via the join operation. This report and that of #15, go hand in hand with the frequency reports of #13.

15. A suggested joins report listing relations having common elements. This could note which relations must be joined to support the functional requirements of the database [5:127]. Also possible is a list of all the other natural joins that are dynamically possible in the database. This can be useful when new applications or functions are added to the database.

16. A redundant attributes report containing a list of data elements appearing as attributes in more than one relation [5:128].

17. A user friendly interactive tool to take a set of

functional dependencies, as specified by the DBA, and reduce the unnormalized relations to Third Normal Form [6]. Such a tool would help the DBA handle this complex and time-consuming task faster, easier, and more effectively.

18. A user friendly (graphical or voice) interface to point to attributes when defining functional dependencies. Such a tool could be especially useful as part of a normalization tool that require the user to specify the functional dependencies for the normalization process.

19. A method for documenting the changes which relations experience during normalization. This could give the DBA and users access to what actually occurred through the execution of the normalization process [6:71].

20. A report stating which relations are affected by the addition of new fields.Such a tool could be useful to the DBA who may need to make trade-offs in design when a new function must be added to the database. It is also useful as an integrity constraint to insure that no relations are inadvertently missed.

21. A tool to generate and help the designer evaluate alternative minimal covers to best suit the organization's needs and/or requirements. This could be a tool to generate the 'best' set of functional dependencies to meet the organization's needs, possibly in terms of performance or convenience.

After considering the utility, feasibility, and appeal of the tools, it was decided to implement tools #17, #18 and #19. Together they compose a complete and useful set of tools for the DBA to use in the design and maintenance of a relational database.

Normalization Tool

The tool to normalize relations is based on the concept of a minimal cover as developed by Ullman. By constructing a minimal set of functional dependencies, the resultant family of functional dependencies is automatically in Third Normal

Form [9:223-225].

The normalization portion of the Normalization Tool consists of 7 major modules and is based somewhat on the pseudo-code developed by Travis [Appendix D]. Each of the modules is sequential in nature and performs a single step in the minimal cover process, with the output of one module becoming the input to the next module.

Ullman states the three requirements necessary for a set of functional dependencies (FDs) to be a minimal cover. First, each FD in the set of FDs can have one and only one dependent attribute (the attribute on the right hand side). This step entails 'breaking out' any functional dependencies that have multiple dependent attributes into as many new FDs as there are dependent attributes in the original FD. The newly created FDs are then substituted for the the original. For example, given the FD ABC --> DE, the result of the first step would be the functional dependencies ABC --> D and ABC --> E. The original relation with two dependent attributes is replaced by two new FDs. The meaning of the first relation has not been lost because later in the process FDs with similar determinant attribute sets can be regrouped.

The second requirement for establishing a minimal cover is to remove redundant functional dependencies. This means removing those FDs that have a subset of determinant attributes that determines the same set of dependent attributes. For example, given the FDs AB --> C and

A --> C, the FD AB --> C should be removed because the FD A --> C conveys the same information. If A --> C by itself then there is no reason to retain AB --> C; it is redundant information.

The third requirement is to remove all transitive dependencies that exist in the set of FDs. A transitive dependency exists if a dependency can be removed from the set of FDs and the resultant set is an equivalent family. For example, given the FDs: A --> B, A --> C, and B --> C, it can be seen that A implies C directly in one FD, as well through attribute B (since A --> B and B --> C). Since a transitivity exists with B and C, the FD B --> C must be removed.

Performing these three steps on a set of FDs guarantees that each dependency, if treated as a relation itself, would satisfy the definition of a relation in 3NF [9:242]. However, because databases strive to reduce data redundancy, the process can be taken two steps further.

First, rather than creating a relation for each of the functional dependencies in the minimal cover, it would be better to first collect those FDs with identical determinant attribute sets into groups. For example, given the set of FDs: A --> B, A --> C, and D --> E, after the minimal cover technique has been applied the first two FDs can be combined to form a single FD (A --> BC). This can result in significant savings in space, especially for large databases.

It is possible to further reduce the number of relations created by realizing that FDs which contain the same attributes (in any order) will result in equal relations. For example, given the FDs A --> BC and C --> BA, the resulting relation in both cases is one containing attributes ABC. Therefore there is no need to create a separate relation for each FD since this would in essence create a duplicate table in the database (and defeat the purpose of the database). This step was not considered in the original design by Travis.

Once these steps have been accomplished, the final step is to actually create separate relation out of each of the remaining FDs. As each FD is created, the system displays the attributes of the FD, along with a list of the current relations in the database, to the DBA so that he/she can input a unique name for the newly created relations.

As an added part of the Normalization Tool, after each step of the process in order to provide the DBA with a step by step view of the FDs as they go through the normalization process. This information is stored in an archive file along with the name of the newly created relations and the old relation definitions, to provide an audit trail in case questions arise in the future about the new relations, the old relations or the functional dependencies that were defined. This information can be very useful in performing joins on the database in order to get back the original

relation. It can also be used as a learning tool to demonstrate the steps in the normalization process.

Methods for Defining Functional Dependencies

There are two main methods which can be used to define functional dependencies: to use some device to 'pick' an option, attribute, etc., or to use some device to input the desired option, attribute, etc. Traditionally the approach taken was that of making the user input the option desired. This method is simpler to implement but is usually not as user friendly. Making the user type in all responses can be an error prone, tedious process. With the advent of various graphics devices there has been an awakening to the concept of user friendliness.

Various devices can be used to input functional dependencies. Among them are a voice input system, touch screen input system, mouse input system, light pen input, keyboard input, and a digitizer pad input system. Regardless of the method used to input FDs, there are several options that can be added for enhancement: color, reverse video, blinking, reordering or indenting attributes that have been selected, and voice feedback.

The selection of functional dependency input methods was based on several criteria: availability of the input device, time available, and usefulness of the device in defining functional dependencies. Of the previously mentioned devices, only the mouse, digitizer pad and keyboard entry are

currently available for use in the LSI-11 lab.

Defining Functional Dependencies: Keyboard Input Method

When an unnormalized relation is found (that contains no data, i.e. tuplecount equals zero), MAIN calls the FD module to query the DBA for the functional dependencies that will be needed for the normalization module. When FD is called, the system displays the message to the DBA:

"Relation xxxx is selected to be normalized", where xxxx is the name of the relation. This is used to inform the DBA of exactly which relation is being manipulated.

Next, a message is displayed to inform the user that the first step is to define the determinant attribute set (the attributes of functional dependencies on the left hand side). The system follows a sequence of steps that entails listing all of the attributes of the relation, asking the user to choose one as a determinant attribute, and then asking if there are any more determinant attributes to be selected.

To aid the DBA in knowing exactly which attributes are in the relation being normalized, the attributes are displayed on the screen four attributes to a line, with 20 lines of display per screen. If more than 80 attributes exist the listing is stopped temporarily when the screen is full in order to give the DBA a chance to review the attributes. When the DBA is ready, the DBA can hit any key for a continuation of the listing. Each attribute is displayed

with a unique identifying number that allows the DBA to reference each attribute without having to type in the name, by typing in it's number instead. By having the DBA type in only the key number of the attribute, the process of specifying functional dependencies is made faster, easier and less prone to typing errors.

When the DBA enters the key number for the attribute he wishes to select, the system checks to make sure that it is a valid attribute number. If it is not a valid key number, the system rejects the input and tells the user that the input just made was out of range, try again. When the DBA inputs a valid key number, the system will find that attribute and then display the name selected to the user to show him the name that was selected (user feedback). The name of the attribute returned is also used to build the functional dependency.

After the DBA inputs a determinant attribute, the system asks if there are any more to determinant attributes to be named. If there are, the DBA types a 'Y', causing the attributes to be displayed again, and then the process of specifying a determinant attribute is repeated. If not, the DBA can type any character other than a 'y' and the system proceeds on to the naming of the dependent attributes (those on the RHS). As with the determinant attributes, the system sends the user an introductory message, a listing of attributes, a query for the naming of an attribute, and then

the question for if there are any more dependent attributes to be named.

When the last dependent attribute of the functional dependency is selected, the system displays the functional dependency just defined and gives the DBA a chance to verify it. If the DBA decides he/she has made a mistake in defining the dependency, the dependency is destroyed. Otherwise, FD makes sure the dependency just defined is not a trivial functional dependency (one such as A --> AB, where an attribute on the determinant side also appears on the dependent side of the functional dependency). If a trivial dependency is found, FD writes a message to the user telling him the dependency was trivial and then removes the functional dependency from the linked list. Once it is determined that the functional dependency specified is valid, the system asks the DBA whether or not there are any more functional dependencies to be defined for the current relation. If there are, the process of defining determinant and dependent attribute sets is repeated until all functional dependencies for the current relation have been defined. Once all the functional dependencies have been defined, control is passed back to MAIN which immediately calls the NORMALIZE module to normalize the relation with respect to the functional dependencies defined for the relation.

Also, after a relation has been normalized, the system asks the DBA if he wants to continue normalizing relations or

end the current session. If the DBA curtails the current session, all of the relations (normalized or not) are written to the output file OUTPUT.DAT. At a later time, the DBA could rerun the normalization tool using the last output file as the new input file. The DBA could then continue to normalize as many unnormalized relations as he wants or has time for. This makes the tool more convenient for the DBA to use.

Defining Functional Dependencies: Mouse Input Method

Using the mouse to input functional dependencies differs from the screen input method. When the mouse input method is used, upon invoking the normalization tool a complete set of instructions is given to the DBA on the first screen and via the Votrax speech synthesizer, informing him how to calibrate the mouse and use it to define functional dependencies.
Every time the mouse is powered up it must be calibrated to orientate it's optics and circuitry to the mouse pad. This can be done easily by moving the mouse diagonally across the mouse pad from the lower left hand corner to the upper right hand corner and then placing it back in it's starting corner (bottom left).
The mouse initialization routine will assure that the mouse has been calibrated and inform the DBA if it has, or tell the DBA to repeat the process again if the mouse has not been properly calibrated.

When an unnormalized relation is found and the mouse

input method is being used, MAIN calls the MOUSE_FD module to query the DBA for the functional dependencies that will be used to normalize the relation. The mouse method, like the keyboard entry method, makes use of two CRTs. One CRT is used to display instructions and prompts to the DBA while the second CRT is used to display the attributes and specify the functional dependencies.

When an unnormalized relation is found, the system displays the message to the DBA: "Relation xxxx is selected to be normalized", where xxxx is the name of the relation. As with the keyboard entry system, this message is used to inform the DBA of exactly which relation is being manipulated.

Next, a message is displayed to inform the DBA that the first step will be to define the determinant attribute set for a functional dependency. The list of attributes are then displayed on the second screen, three attributes to a line and a new line every other line, for a total of 24 attributes per screen display. If there are more attributes the DBA can press the middle key of the mouse to get an additional listing. The reason that only 24 attributes are listed per screen in the mouse method (as opposed to 80 in the keyboard entry system), is to make it easier for the DBA to select attributes by moving the mouse. If too many attributes are displayed at once, the screen will become too cluttered for the DBA to be able to manipulate the cursor position via the

mouse in order to select an attribute.

With the attributes displayed on the second screen, the DBA can now proceed by moving the mouse along the mouse pad (which correspondingly moves the cursor) until he comes upon the desired attribute. When moving the mouse it is important to keep it on the pad at all times.

To select the desired attribute the DBA presses the center key on the mouse which causes the selected attribute to be displayed in reverse video in order to show the DBA which attribute she/he selected.

After a determinant attribute has been selected the system asks the DBA if there are any more determinant attributes to be named. This is done via the first screen and the Votrax (in order to get the DBA's attention). The DBA can answer the system's questions by pressing the left key on the mouse for 'no' and the right key for a 'yes'. The system will wait until there is a change in the status of either the left or right keys. If there are more determinant attributes to be specified, the attributes are displayed again and the process is repeated.

When all of the determinant attributes for a functional dependency have been specified the system proceeds to the naming of the dependent attributes. The procedure is exactly the same as with the determinant set except for the system message (via the first screen and Votrax) telling the DBA to select dependent attributes.

After the last dependent attribute of the functional dependency has been specified, the system gives the DBA the chance to verify the functional dependency and then checks to make sure the functional dependency specified was not trivial and removes it if it is. Then the system asks the DBA (via the first screen and the Votrax) if there any more functional dependencies to be defined for the current relation. If there are, the DBA presses the right key on the mouse and the process of defining determinant and dependent attributes is repeated until all functional dependencies for the current relation have been defined. Once all functional dependencies have been defined, the functional dependencies are written to a file. Control is then returned to MAIN who then closes files and completes execution. The actual normalization is done by executing another program (P2NORM) which then reads the functional dependencies and calls the NORMALIZE module to normalize the relation with respect to the functional dependencies defined for the relation. Using the mouse to define the functional dependencies that are subsequently used to normalize relations is a two-step process because of the size of the code needed and the memory limits of the LSI-11 systems.

APPENDIX C

Peripheral Devices

This appendix contains a description of the various peripheral devices used in this thesis effort. The devices presented are the Summamouse, Votrax speech synthesizer, and the Cleveland Cadonics Graphics card. The discussion of each is meant to highlight the most pertinent details. For a more complete description the reader should refer to the cited manuals.

The Summamouse

Introduction. The mouse used in this thesis effort was a Summagraphics Corporation Summamouse. It was selected only because of it's availability, not for any technical superiorities. As a matter of fact, the Summamouse has one drawback: it must be carefully calibrated before each use in order to establish the origin at (0,0). This is explained in more detail in the section on interfacing, presented later in this appendix.

The Summamouse operates on a 'mouse pad' that has two perpendicular sets of stripes, .5mm wide, spaced on 1mm centers. These sets of stripes absorb different wavelengths of light, infrared and red. Infrared-absorbing stripes run along the eleven inch length of the mouse pad, and red-absorbing stripes run the nine inch width. In addition to

sending back information about X and Y coordinates, the mouse also has three action keys which can be defined by the user.

Calibrating the Mouse. Every time the mouse is powered-up, it must be calibrated to orientate it's optics and circuitry to the mouse pad. The mouse pad can be positioned in either portrait orientation (mouse pad width is less than it's length) or in landscape orientation (mouse pad width is greater than it's length). In either case, the mouse must be placed on the mouse pad with the action keys facing away from the user.

To orientate the mouse, it must be moved diagonally across the mouse pad, from the lower left-hand corner to the upper right-hand corner. Within one second the mouse will compensate for changes in it's optics and will be prepared to send data to it's host.

Configuring the Summamouse. The Summamouse can be configured, by remote commands sent from the host, to send data in various ways. A copy of the remote commands for setting these operating characteristics appears in Table II. The baud rate of the Summamouse is either set at the factory or equipped with the auto-baud rate feature. The mouse used in this thesis has the auto-baud rate feature that sets the mouse's baud rate equal to that of the host. Every time the mouse is powered-up, the baud rate must be set by sending the mouse an ASCII SPACE character.

Table II
Summamouse Remote Settings [8:4]

OPERATING CHARACTERISTICS	ASCII CHARACTERS	HEX NUMBER
Auto Baud	SPACE	20
(receive from Summamouse)	ACK	06
Output Report Rates:		
10 characters per second	J	4A
20 " "	K	4B
35 " "	L	4C
50 " "	R	52
70 " "	M	4D
*100 " "	Q	51
140 " "	N	4E
Remote Request Mode	D	44
Remote Trigger Command	P	50
Resolution:		
Dynamic	x	78
*Linear	1	6C
Transmission Control:		
Stand-by	ESC DC3	13
Resume Transmission	ESC DC1	11
Status	s	73
Diagnostics	ENQ	05
Echo	k	6B
Reset	nul	00

* The Summamouse defaults to this setting, in Incremental Stream mode.

There are two methods to receive data, incremental stream mode or remote request mode. In Incremental stream mode, X,Y coordinates and action key data are sent to the host automatically every time the mouse moves or an action key is pressed or released. A much simpler method to write driver software is the remote request mode, where the mouse transmits an output report only when the host sends the ASCII P remote trigger command. In order to use remote request mode, the user must first send the mouse an ASCII D to get into the mode.

One of the features of the Summamouse that came in very useful in this effort in the interfacing/software debugging effort, was the status request command, ASCII s. When the command is sent, the mouse sends back one status byte of information as shown in Table III.

Table III
Status Data Format [8:8]

BIT	IF 0	IF 1
0	Uncalibrated	Optics calibrated
1	Orientation not established	Orientation established
2	Portrait orientation	Landscape orientation
3	Special format	Regular format
4	Infrared LED operating	Infrared LED failure
5	Red LED operating	Red LED failure
6	Incremental stream mode	Remote request mode
7	Not used	Not used

Note that the data is sent with bit 0 as the least significant bit (LSB). In this effort, the status byte received was a 4f in hex, or in other words all bits were set to 1 except for bits 4, 5, and 7.

Interfacing Information. To communicate with the mouse, the host computer sends remote commands to the Summamouse over a full duplex, asynchronous, serial, EIA-RS232-C interface. The mouse then sends back output reports of movement in the X and Y directions in order to update the screen cursor. The Summamouse is set up at the factory to send the information to the host in one of 4 different formats.

It was this last bit of information, or lack thereof, that caused many hours of confusion. It seems that nowhere in the Summamouse technical manual does it tell the user what format the mouse is set up for. After calling the Summagraphics office and speaking to one of their engineers, it was finally established that the mice here at AFIT use the non-standard Bit Pad One Data Format. The way to tell what kind of a mouse it is, is to pick it up, look underneath it for the UPC bar code, and read the first 2 digits. A first digit of 2 signifies RS232 format, as opposed to the optional TTL interface. The 1 for the second digit signifies the Bit Pad One Data Format. The Bit Pad One Data format itself presents some inherent problems. In the Bit Pad One emulation, the Summamouse communicates with the host in the form of 5 8-bit binary bytes. Each byte contains 7 data bits and an even parity bit. One start bit precedes each byte, and the parity bit and one stop bit follow each byte.

In Bit Pad One format, the mouse mimics the Bit Pad One

digitizer. The mouse collects 'absolute' positions for coordinates limited to values between 0 and 4096. The mouse sends 5 bytes of information every time a remote trigger command is sent. The first byte contains action key data and has a 1 in the sixth bit for use as a phasing bit. The second and third bytes contain the X coordinate; the fourth and fifth bytes contain the Y coordinate. The Bit Pad One format is shown in Table IV below.

Table IV
Bit Pad One Data Format

Stop Bit	P	6	5	4	3	2	1	0	Start Bit
1	P	1	0	L	M	R	0	0	0
1	P	0	X5	X4	X3	X2	X1	X0	0
1	P	0	X11	X10	X9	X8	X7	X6	0
1	P	0	Y5	Y4	Y3	Y2	Y1	Y0	0
1	P	0	Y11	Y10	Y9	Y8	Y7	Y6	0

Key:

P = Parity (even)
Bit 6 = Phasing bit
1 identifies the first byte in the format
0 identifies subsequent bytes
L = Left key
M = Middle key
R = Right key
L,M,R = action key indicators: 1= key pressed
0= key not pressed
X0-X11 = X bits
Y0-Y11 = Y bits
X0,Y0 = Least significant bit

No sign bits are used in the Bit Pad One format because the mouse collects "absolute" positions. When the mouse moves in a 'positive' direction it counts up from low numbers

to high numbers, and likewise, when the mouse moves in a 'negative' direction it counts down from high numbers to lower numbers.

The big problem is to correctly set the origin to (0,0) on the mouse pad, in order to get full use of the corresponding CRT size. Before each use, after calibrating the mouse, the origin must be set by performing the following ritual. First move the mouse to the lower left hand corner of the mouse pad. Then lift the mouse up to the upper right hand corner and move it to the lower left hand corner again. This ritual must be repeated until the X and Y coordinates are 0,0. Then the mouse can be lifted and placed anywhere on the pad, thereby establishing the origin (0,0) at that location (usually the bottom left hand corner).

While receiving absolute coordinates is a bonus to software development, the ritual that must be performed every time the system is powered up is tedious, for it is challenging for the average user to get the origin (0,0) in it's proper location in order to make full use of the CRT.

Finally, for better performance, the mouse pad should be cleaned often with glass cleaner and a soft cloth. The optical apertures on the bottom of the mouse should also be cleaned by blowing out any dirt and wiping the sensor area carefully with a Q-tip. No other solvents besides a mild detergent should ever be used on the mouse.

Votrax Speech Synthesizer

The Votrax Type 'N Talk (TNT) is an easy to use voice synthesizer. It is connected to the system via an RS-232 serial port. The Votrax contains a synthesizer chip and a text-to-speech translation system that creates speech from a set of rules describing English, rather than a set of stored utterances. As such, it is possible to any high level programming language to send ASCII text strings directly to the Votrax to speak while the system performs other functions.

Text can be sent to the Votrax at 75-9600 baud and is stored in the Votrax's input buffer until full or until a 4 second time out occurs after the last character is sent. Since the Votrax is a compact system and English is such a complex language, the Votrax is not capable of producing the most acceptable pronunciations for all words. This can be corrected by the user in several ways. One way is to misspell the word to make it more phonetically correct. The Votrax user's manual supplies a pronunciation correction guide to make the task easier [11:20]. For example, the first vowel of the word "English" is not accurately pronounced by the Votrax. In order to correct this, the user would misspell the word as "inglish". The second method is to break a long word such as "baseball" into two separate words, "base ball".

There is a third alternative, phonetic programming, where

the user sends a word created from a list of phoneme symbols. This method is much more complicated and is recommended as a last resort. With a little practice, it was not difficult to find an acceptable pronunciation for all of the words used as user feedback in this thesis.

Cleveland Cadonics Graphics Card

Introduction. With the Cleveland Cadonics card there are four different operational modes that can be used with the H-29 graphics terminal. The modes available are Native Graphics mode, Standard Terminal Alphanumeric mode, Alphagraphics mode and Tektronics mode. Upon power-up, when the terminal is reset, when a software reset is sent, or when he keyboard is reset, the terminal will exit from graphics mode and go into the standard terminal alphanumeric mode. When this is done, the graphic's video RAM gets cleared and all graphics parameters are set to their default values.

In order to switch from one mode of operation to another, the software must send the appropriate command to the terminal. Figure 11 below shows the commands needed to move from one mode to another. For example, in order to move from standard terminal alphanumeric mode to Tektronics mode, a GS must be sent. Each of the four modes is discussed in the sections that follow.

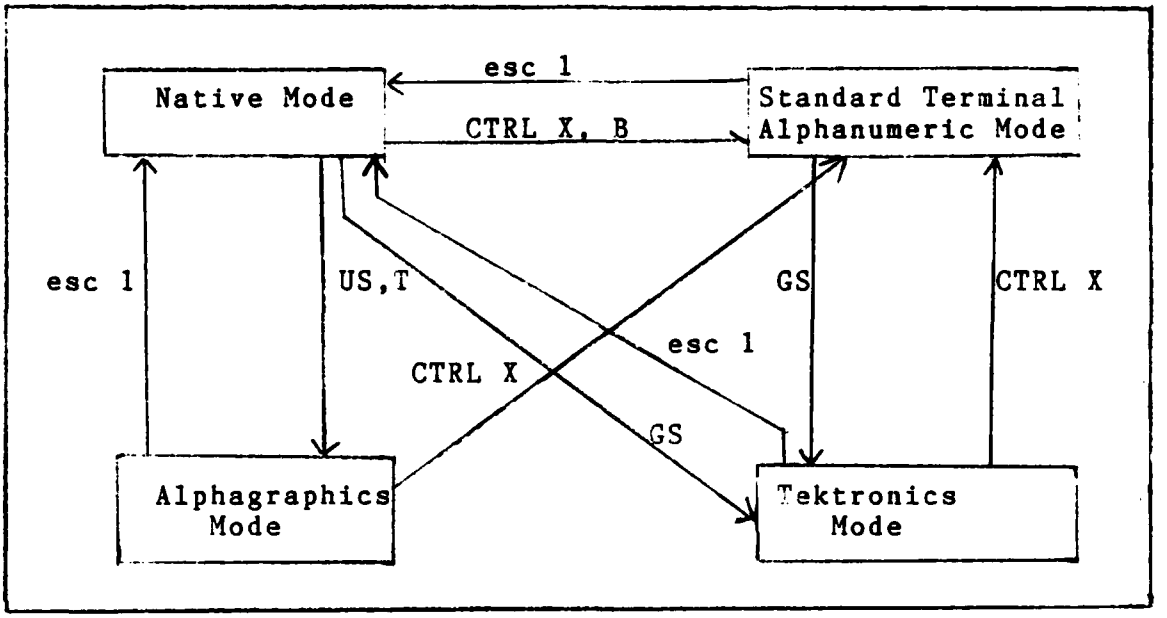


Figure 11
Modes of Operation and their Transition Commands [3:5]

1. Standard Terminal Alphanumeric Mode. The standard terminal alphanumeric mode is the terminal's default mode. Simply put, it is the mode that the H-29 terminal normally works in. For a more complete description refer to the Heathkit H-29 manual.

2. Native Mode. Native graphics mode is the mode where all native graphics commands are usable. It is based on two main commands, move commands and line (draw) commands.

A move-to command sets or changes the current screen position of the virtual pointer. Nothing is written to the screen when a move is executed. There are three kinds of moves: absolute, relative and a combination of the two. For example, an absolute command to move the virtual pointer

to X=30, Y= 100, relative to the position of the origin, would be M30,100,. To move the virtual pointer a specified distance from its current position, a relative move is used. The command is identical to an absolute move, with the addition of a +/- delimiter used before the X,Y values. For example, if the virtual pointer is at X=90, Y=50, and a move command is executed as M+10,-25, the new virtual pointer will be at X=100, Y=25.

The Line commands also come in the same three formats. When a line command is executed, a straight line is dra... from the virtual pointer location to the new coordinate specified by X and Y. For example, the command L-10,+50, will subtract 10 from the X coordinate of the virtual pointer position, add 50 to the Y coordinate, and draw a line between the two points. The virtual pointer is also updated to the new X,Y position.

Other commands available include a point-at command to draw a point, a rectangle command to draw a rectangle, an area command to draw a filled regular area, an erase command, and several commands to set line attributes and perform hardware zooming and panning.

3. Alphagraphics Mode. The main purpose for alphagraphics mode is to be able to label and enter text on graphics displays. This is done by entering alphagraphics mode and sending the desired text as character strings from the host computer, in the same manner that they would be sent

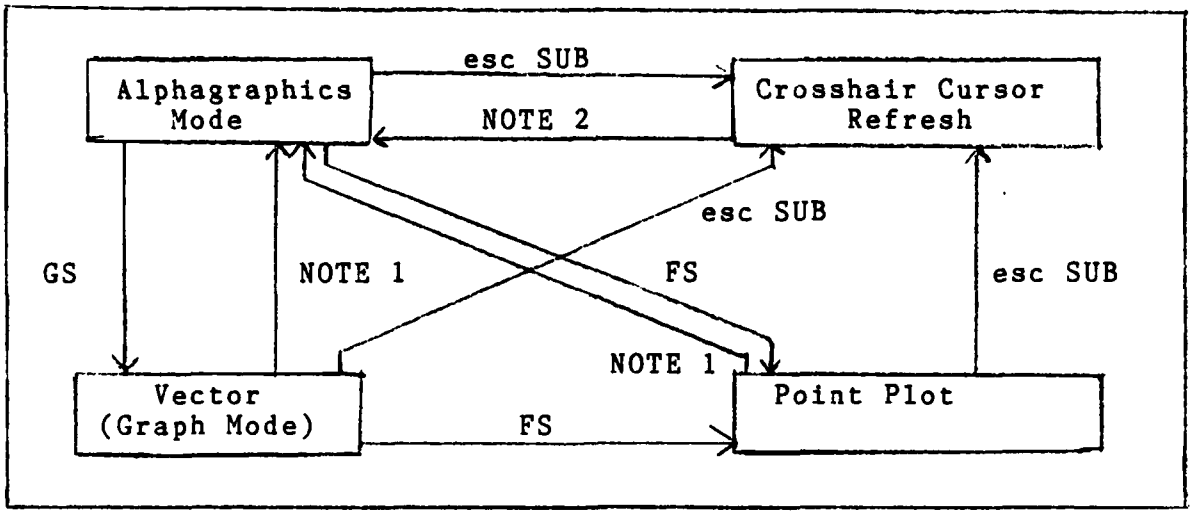
to a standard alphanumeric terminal from the user's program. All characters that appear are subject to the current character orientation, text spacing, and character zoom size parameters that are determined in the Native mode.

4. Tektronics Mode. Tektronics mode is one of the most powerful and most versatile modes. The Tektronics mode supports the following features:

* Alpha mode
* Vector and Point modes
* Crosshair cursor refresh
* Multi-sized hardware text characters
* Selective erase
* Screen read
* Vector line style selection
* User definable text parameters such as character orientation, text spacing, and zoom character attributes
* All Native mode commands.

In order to use the features available in Tektronics mode, control commands are sent as shown on the next page in Figure 12.

Alphagraphics Mode. The Alphagraphics mode allows the user to display any of 95 printable characters in lower or upper case. Upon entry into Alphagraphics mode the character size is set to 1. If the user desires to change the character size, he can enter Native mode and change the character zoomsize select number.



*Note 1: US, CR, esc FF, or keyboard RESET.
*Note 2: CR, esc FF, or keyboard RESET.

Figure 12
Tektronics Operating Mode Changes [3:39]

Vector Mode. Vector mode is where most of the drawing takes place. When in Vector mode, all ASCII characters sent to the terminal are interpreted as coordinates for a vector line to be drawn. The first coordinate corresponds to the Native mode Move command and sets the cursor to the beginning of the line. The second coordinate corresponds to the Line command and draws a line from the first point to the second. A vector can be drawn that does not connect to the previous vector by preceding the first endpoint by a GS control code, which has the effect of reinitializing the vector drawing sequence.

The coordinates for the line to be drawn must be sent to the terminal in the following order and format:

High Y byte:	P	0	1	Y9	Y8	Y7	Y6	Y5
Low Y byte:	P	1	1	Y4	Y3	Y2	Y1	Y0
High X byte:	P	0	1	X9	X8	X7	X6	X5
Low X byte:	P	1	0	X4	X3	X2	X1	X0

The first two bytes make up the Y coordinate, and the last two bytes make up the X coordinate.

Point Plot Mode. The Point plot mode is very much like the Point command available in Native mode. When a coordinate is sent to the terminal while in Point plot mode, a point is drawn at that location on the screen. The format for sending coordinates is identical to the one used in Vector mode.

Crosshair Cursor Mode. When in this mode, a full screen crosshair cursor appears on the screen. This cursor can be moved around the screen by hitting one of the four cursor control keys on the keyboard (arrow keys). Hitting one of these keys causes the crosshair to move one pixel; hitting one of these keys with the SHIFT key causes the crosshair to move 16 pixels in the given direction.

When in Crosshair Cursor mode, striking any key other than the arrow keys will cause the cursor to disappear, and the value of that key and the coordinates of the current cursor position are sent to the host computer and are echoed back to the terminal where they are accepted as graphic data. It is possible to turn off the echo feature if desired.

APPENDIX D

Program Design Language Code for NORMALIZE Submodules

This appendix contains the original pseudo code used as the basis for the normalization process used in this thesis. The pseudo code, developed by Travis [6], uses the concept of a minimal cover to normalize relations into Third Normal Form. The six modules presented are: HIGH_LOW, BREAKOUT, RMOVE_SUBS, RMOVE_TRANS, REGROUP, and NEW_REL.

HIGH_LOW sorts functional dependencies in descending order but was not used in this effort because its only purpose was to make the programming of RMOVE_TRANS easier and it was deemed that it was not worth the time or effort.

BREAKOUT insures that each functional dependency contains only one attribute in the dependent attribute set. RMOVE_SUBS removes dependencies that have subsets of determinant attribute(s) as determinant attributes in other functional dependencies which determine the same single dependent attribute. RMOVE_TRANS searches the linked list of functional dependencies and then removes them. REGROUP consolidates into a single functional dependency, all dependencies that have similar determinant attribute sets. NEW_REL creates new relations from the regrouped functional dependencies.

It should be noted that the final design used six modules

as in Travis' design, but the normalization process used in this thesis does not use the HIGH_LOW module. Instead, this process added a module, REMOVE_DUPL, which removes duplicate functional dependencies that contain the exact same attributes (since the resulting relations created would be identical).

Also, the pseudo code developed by Travis was not entirely correct or complete, and was modified and improved during the implementation of this thesis. For details of the changes see the Normalization Implementation section in Chapter III.

Module HIGH_LOW

```
(*************************************************************
*  PURPOSE  :  Sort FDs of the relation that NREL points to  *
*              in a descending order, by the number of       *
*              attributes in each FD's determinant           *
*              attribute set.                                *
*                                                            *
*  GLOBAL VARIABLES USED:                                    *
*     NREL - pointer to relation in question.                *
*                                                            *
*  GLOBAL VARIABLES MODIFIED  :  None                        *
*                                                            *
*************************************************************)

PROCEDURE HIGH_LOW

BEGIN
  USE QUICK SORT METHOD FOUND IN FUNDAMENTALS OF DATA
      STRUCTURES, HOROWITZ and SAHNI, COMPUTER SCIENCE
      PRESS, 1976, pp 347-350

END.
```

Module BREAKOUT

```
(*************************************************************
*  PURPOSE:  Insure that each functional dependency (FD)     *
*            contains only one attribute in the dependent    *
*            attribute set.  This is accomplished by tra-    *
*            versing the linked list of FDs, selecting those*
*            that contain two or more attributes in the      *
*            dependent set, and then creating "new"          *
*            (equivalent) FDs that have the same determi-    *
*            nant set of attribute(s) with a single attri-   *
*            bute as the dependent set (i.e., the FD         *
*            "A B C -- D E" would produce the FDs            *
*            "A B C -- D" and A B C -- E").                  *
*                                                            *
*  GLOBAL VARIABLES USED:                                    *
*     NREL - pointer to relation in question                 *
*     TFD  - functional dependency record structure          *
*     PART - attribute record structure                      *
*                                                            *
*  GLOBAL VARIABLES MODIFIED:  None                          *
*                                                            *
*************************************************************)

PROCEDURE BREAKOUT

BEGIN
  SET TPTR1 TO NREL^.NEXTFD     (* head of list *)
  DOWHILE TPTR<>NIL
    BEGIN
      DOWHILE NUMBER DEPENDENT ATTRIBUTES > 1
        BEGIN
          CREATE NEW FD STRUCTURE
          MOVE DETERMINANT SET TO NEW STRUCTURE
          MOVE 1st DEPENDENT ATTRIBUTE TO NEW STRUCTURE
          REMOVE 1st DEPENDENT ATTRIBUTE FROM TPTR1^.toptr
                list
          INSERT NEW FD STRUCTURE INTO FD LIST
        ENDDO
      ADVANCE TPTR1 DOWN FD LIST ONE RECORD
    ENDDO
END.    (*  BREAKOUT  *)
```

Module RMOVE_SUBS

```
(*************************************************************
*  PURPOSE:  Remove dependencies which have subsets of      *
*            determinant attribute(s) as determinant        *
*            attributes in other functional dependencies    *
*            which determine the same single dependent      *
*            attribute.                                     *
*                                                           *
*  GLOBAL ATTRIBUTES USED:                                  *
*     NREL - pointer to relation in question                *
*                                                           *
*  GLOBAL VARIABLES MODIFIED:  None                         *
*                                                           *
*  INTERNAL VARIABLES USED:                                 *
*     MAINPTR - pointer to FD in question                   *
*     AUXPTR  - pointer to possible subset FD               *
*                                                           *
*************************************************************)

PROCEDURE RMOVE_SUBS

BEGIN
  SET MAINPTR TO 1st FD   (* head of list *)
  SET AUXPTR TO MAINPTR^.NEXTFD
  DOWHILE MAINPTR^.NEXTPTR<>NIL
    BEGIN
      DOWHILE AUXPTR<>NIL
        BEGIN
          IF MAINPTR^.TOPTR^.PARTNAME EQUALS
               AUXPTR^.TOPTR^.PARTNAME THEN
            IF AUXPTR DETERMINANT SET IS SUBSET OF MAINPTR
                  DETERMINANT SET THEN
              REMOVE MAINPTR FD
          ADVANCE AUXPTR ONE FD DOWN LIST
        ENDDO
      ADVANCE MAINPTR ONE FD DOWN IN LIST
      SET AUXPTR TO MAINPTR^.NEXTPTR
    ENDDO
END.
```

Module RMOVE_TRANS

```
(*************************************************************
*  PURPOSE:  Searches linked list of FDs to find tran-      *
*            sitive dependencies and remove them.           *
*                                                           *
*  GLOBAL VARIABLES USED:                                   *
*     NREL - pointer to relation in question                *
*                                                           *
*  GLOBAL VARIABLES MODIFIED:  None.                        *
*                                                           *
*  INTERNAL VARIABLES USED:                                 *
*     MAINPTR - pointer to possible 1st dependency of       *
*               transitive dependency.                      *
*     SNGLPTR - pointer to 1st dependency in list that has *
*               single attribute in determinant set         *
*     AUXPTR1 - extra pointer                               *
*     AUXPTR2 - extra pointer                               *
*                                                           *
*************************************************************)

PROCEDURE RMOVE_TRANS

BEGIN
  SET SNGLPTR TO 1st FD WITH SINGLE DETERMINANT SET
  SET MAINPTR TO 1st FD IN LIST   (*  head of list  *)
  DOWHILE MAINPTR^.NEXTFD<>NIL
    BEGIN
      DOWHILE AUXPTR1.NEXTFD<>NIL
        BEGIN
          SET AUXPTR1 TO SNGLPTR
          SET AUXPTR2 TO SNGLPTR
          IF MAINPTR DEPENDENT ATTRIBUTE SET EQUALS
             AUXPTR1's DETERMINANT ATTRIBUTE SET THEN
            DOWHILE AUXPTR2<>NIL
              BEGIN
                IF AUXPTR2's FD EQUALS FD MADE UP OF
                   (MAINPTR's DETERMINANT SET AND AUXPTR1's
                    DEPENDENT SET) THEN
                  REMOVE AUXPTR2's FD
                ADVANCE AUXPTR2 DOWN LIST ONE RECORD
              ENDDO
          ADVANCE AUXPTR1DOWN LIST ONE RECORD
        ENDDO
      ADVANCE MAINPTR DOWN LIST ONE RECORD
    ENDDO
END.
```

Module REGROUP

```
(*************************************************************
*  PURPOSE:  Consolidation into a single functional         *
*            dependency all dependencies that have sim-     *
*            ilar determinant attribute sets.               *
*                                                           *
*  GLOBAL VARIABLES USED:                                   *
*     NREL - pointer to relation in question                *
*                                                           *
*  GLOBAL VARIABLES MODIFIED: None.                         *
*                                                           *
*  INTERNAL VARIABLES USED:                                 *
*     MAINPTR - pointer to FD in question                   *
*     AUXPTR  - pointer to possible FD to be joined         *
*                                                           *
*************************************************************)

PROCEDURE REGROUP

BEGIN
  SET MAINPTR TO HEAD + 1 OF FD LIST
  SET AUXPTR TO HEAD + 1 OF FD LIST
  DOWHILE MAINPTR^.NEXTFD<>NIL
    BEGIN
      DOWHILE MAINPTR's DETERMINANT SET EQUALS AUXPTR's
              DETERMINANT SET
        BEGIN
          ADD AUXPTR's DEPENDENT ATTRIBUTE(S) TO MAINPTR's
               DEPENDENT ATTRIBUTE SET
          DISPOSE OF AUXPTR's FD   (*  remove it  *)
        ENDDO
      ADVANCE MAINPTR DOWN LIST ONE FD RECORD
      SET AUXPTR TO MAINPTR
    ENDDO
END.
```

Module NEW_REL

```
(*************************************************************
*  PURPOSE:  Create relations from to regrouped              *
*            functional dependencies                         *
*                                                            *
*  GLOBAL VARIABLES USED:                                    *
*     NREL - pointer to relation in question                 *
*                                                            *
*  GLOBAL VARIABLES MODIFIED:  None                          *
*                                                            *
*************************************************************)

PROCEDURE NEW_REL

BEGIN
  DOWHILE NREL^.NEXTFD<>NIL
    BEGIN
      CREATE RELATION STRUCTURE
      SET NORMALIZE SWITCH TO "ON"
      DISPLAY ATTRIBUTES
      QUERY DBA FOR NEW RELATION NAME
      BUILD ATTRIBUTE LIST FROM FD's DETERMINANT AND
            DEPENDENT SETS
      LINK KEYPTR LIST FROM FD's DETERMINANT SET
      SET NEXT FD TO NIL
      SET SECURITY RECORD FROM NREL SECURITY RECORD INFO
      SET MODIT, TEMPEXIST, and ATTACH FROM NREL's INFO
      SET FILER FROM NREL's FILER
      INSERT THIS NEW RELATION INTO RELATION LIST
         IMMEDIATELY BEHIND NREL's RELATION
      DISPOSE OF NREL^.NEXTFD  (* remove head fd from list *)
    ENDDO
END.
```

VITA

2Lt. Edward R. Jankus was born October 11, 1961, in Chicago, Illinois. He attended high school there and in 1979 attended Illinois Institute of Technology from which he received the degree of Bachelor of Science in Computer Science in May 1983. Upon graduation he received an ROTC commission in the USAF and entered the School of Engineering, Air Force Institute of Technology, as his initial assignment.

Permanent Address: 7031 S. Fairfield
Chicago, Illinois 60629

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): AFIT/GCS/EE/84D-10	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: School of Engineering; 6b. OFFICE SYMBOL (If applicable): AFIT/ENG	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State and ZIP Code): Air Force Institute of Technology, Wright-Patterson AFB, Ohio 45433	7b. ADDRESS (City, State and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: Rome Air Development Center; 8b. OFFICE SYMBOL (If applicable): RADC/COTD	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code): HQ Rome Air Development Center, Griffiss AFB, New York 13441	10. SOURCE OF FUNDING NOS. — PROGRAM ELEMENT NO. / PROJECT NO. / TASK NO. / WORK UNIT NO.
11. TITLE (Include Security Classification): See Box 19	
12. PERSONAL AUTHOR(S): Edward R. Jankus, B.S., 2d Lt, USAF	
13a. TYPE OF REPORT: MS Thesis; 13b. TIME COVERED: FROM _____ TO _____; 14. DATE OF REPORT (Yr., Mo., Day): 1984 December; 15. PAGE COUNT: 142	
16. SUPPLEMENTARY NOTATION	
17. COSATI CODES — FIELD: 09; GROUP: 02; SUB. GR.:	18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Data Base, Computer Aided Design, Computer Programs, Relational Databases, Theses

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Title: DEVELOPMENT OF COMPUTER AIDED DATABASE DESIGN AND MAINTENANCE TOOLS

Thesis Chairmain: Dr. Thomas C. Hartrum

Approved for public release: IAW AFR 190-17.
21 Feb 85
LYNN E. WOLAVER
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr. Thomas C. Hartrum	22b. TELEPHONE NUMBER (Include Area Code): 513-255-3576; 22c. OFFICE SYMBOL: AFIT/ENG

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

This thesis investigated what the tasks of the database administrator are and detailed a list of computer aided tools to assist the database administrator in performing those tasks. A selection criteria was established and two of the tools were implemented.

The first tool implemented was an interactive user-friendly Automated System for Normalizing Relations into Third Normal Form. The basis for this tool is the concept of a minimal cover as presented by Jeffrey Ullman. If a minimal cover is deduced from the set of functional dependencies of an unnormalized relation, the resultant relations are in Third Normal Form.

The second tool explores the user-friendly graphics area. It is a new front-end to the normalization tool that uses a mouse to allow the database administrator to specify the functional dependencies that go into the normalization process. Together, these tools provide a very useful and complete tool for the database administrator to normalize relations in a Relational Database.

END

FILMED

5-85

DTIC